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HIGHWAY RESEARCH REPORT

RE-EVALUATION OF THE PROBLEM

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STATE OF CALIFORNIA

TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

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STATE OF CALIFORNIA
Department of Public Works
Division of Highways
Materials and Research Department

February 10, 1967

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Mr. J. C. Womack
State Highway Engineer
Division of Highways
Sacramento, California

Dear Sir:

Submitted for your consideration is:

REPORT

ON A

RE-EVALUATION OF THE PROBLEM

CONCERNING

EXPANSIVE SOILS UNDERLYING

PORTLAND CEMENT CONCRETE PAVEMENTS

Study made by . . . . Pavement Section
Under the general direction of. . . . . Ernest Zube
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Report prepared by. . . . . Ernest Zube
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Very truly yours,

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INTRODUCTION

In our experience with portland cement concrete (PCC) pavements, over the past 30 years, there have have been scattered instances where severe slab distortion has occurred as a direct consequence of differential expansion in underlying soils. The condition manifests itself in the form of warping or curling of the slabs with an uplift at the joints and edges. Cases have been noted where joints were elevated in excess of 3/4 inch above midslab. Deformations of this magnitude completely destroy the good riding qualities of a road and often precipitate subsequent forms of distress such as corner or midslab cracking, joint pumping and joint faulting.

The phenomenon of concrete slab distortion is not always caused by external forces such as swelling soils. Thermal and/or moisture differentials normally existing between the top and bottom surfaces of concrete pavements, can also result in some slab warping. However, the magnitude of the deformation from these causes are generally moderate and due to constantly changing ambient moisture and temperature conditions will in effect alternately supplement and oppose externally caused slab curling. In any event, the volume change behavior of concrete is a separate problem and the discussions, which follow in this report, will concern pavement curling caused primarily by the uplift of differentially expanding soils.

The mechanism responsible for the curling of PCC pavements involves a sequence of conditions and events which are given as follows:

A. First is the presence of clayey sub-soils (usually the basement soil) which possess a high potential for expansion at the time the pavement is laid. The reasons for this potential, in any given case, are usually due to one or more of the following conditions:

   1. Inherently high expansion properties of the soil even after reaching relatively high moisture levels. A heavy bentonitic or nontronitic clay (montmorillonite class) has this characteristic to a marked degree.

   2. Compaction of soils in a too-dry condition. This can apply to soils which have only low or moderate expansive capacity at the higher moisture levels.

   3. The drying out of the compacted soil prior to the placing of the surface courses.

B. Secondly, it is characteristic of concrete slabs to shrink and thereby develop cracks over a period of time after placement. In California, PCC pavements are being constructed with transverse weakened plane joints at approximately 15 foot intervals which are either preformed or saw cut. Within a matter of days (and sometimes hours) shrinkage of the concrete causes the slabs to crack through at the joints, usually starting at alternate joints spaced 30 or 45 feet apart and subsequently including most of the intervening joints. Investigation of "open" joints, by coring through both the pavement and base, has revealed that in many cases the underlying cement treated base (CTB), including the bituminous curing seal, also cracks through in the vicinity of the joint crack. This provides an open channel through pavement and CTB to the more or less pervious subbase layer. Shrinkage and movement of the slabs at the pavement edges also provide a channel for water to enter.

C. Finally, the intrusion of surface water through the open joints and at pavement edges, from precipitation after the concrete is placed, completes the chain of events. Water passing through the joints and along the edges to the underlying expansive soil, creates a differential swell which bends the pavement sharply upward at the slab ends and edges. Generally this excessive curling will take place within one year after construction, although it may be delayed longer. If the sequence of events leading to slab curl are delayed, or do not take place for some reason, then the soil will tend to take up water uniformly and the entire pavement will be uplifted more or less evenly (if uniform, the uplift is of no particular concern).

The non-uniform distribution of moisture which leads to differential volumetric expansion in soils underlying PCC pavements, and consequently slab curl, does not normally develop under bituminous type structural sections. In the latter case, moisture generally enters the section in a relatively uniform manner, regardless of the path of entry. The only concern with bituminous structural sections is the effect that expansion may have on the stability (R-value) of the soil rather than any direct consequence from the vertical movement of the roadbed. The effect on stability is a separate problem and is accommodated in design through expansion pressure measurements in the R-value test (6).

To date six major PCC pavement projects, investigated by the California Division of Highways, exhibited serious curl from expansive subgrade soils. These projects are listed chronologically as follows:

1. 03-Col-7; Williams to Maxwell, constructed in 1931 (1).

2. 07-LA-26; near Pomona, constructed in 1933 (2).

3. 07-Ora-184-S.Ana; South Main Street in Santa Ana, constructed in 1936.

4. 07-Ora-171-A,Hnt. B; Huntington Beach to Garfield Street, constructed in 1937.

5. 04-SCl, Ala-69-A,E; Gish Road to Warm Springs, constructed in 1953. (3)

6. 05-Mon-2-Sal; Salinas Bypass constructed in 1954. (4)

While the above projects represent the most pronounced cases, there are undoubtedly pavements which have experienced difficulties to a lesser extent and have lost some of their initial riding quality prematurely.

As a result of the Warm Springs (Project 5 above) investigation, a method of test and analysis was developed by the Materials and Research Department for application to both design and construction. This method was intended as an interim measure and was outlined in a Circular Letter dated October 29, 1954 (5). Shortly after the method went into effect, it became apparent that abnormally heavy concrete structural sections were being required in many areas where previously constructed sections of lesser thickness had served without evidence of curl for many years. In addition, construction difficulties were being experienced in attaining required minimum moisture levels, particularly to the depth of four feet below profile grade, which was a part of the instructions. Admittedly, the method has proved to be quite conservative but it was, however, considered expedient at that time to present a method which would provide a solution to the problem of expansive soils well on the safe side.

It is the purpose of this report to reassess the behavior of expansive soils in connection with PCC pavements on the basis of subsequent extensive research studies and accumulated experience. In addition, a new test method will be presented for use in the solution of future design and construction problems.

SUMMARY AND CONCLUSIONS

1. In order to minimize the chance of curling of PCC slabs, the control of expansive soils should be accomplished through design by providing sufficient restraining weight of cover and in construction, by adequate watering to attain minimum moisture levels established by design.

2. Since PCC curl is fundamentally a volume change phenomena, the linear expansion test provides a suitable means of establishing the relationship between field performance and laboratory testing.

3. The volume change experiments given in this report have proved that the third cycle expansion pressure test is more reliable than a one-cycle test in discriminating between relatively low volume change silty soils and the high volume change clay soils.

4. A practical advantage of the third cycle test is that it may be performed by our district laboratories without requiring any modification or alterations of the existing expansion pressure devices.

5. The third cycle expansion pressure test and attendant allowable values are satisfactory for application to the design and construction control of expansive soils under PCC pavements.

6. The procedures for the testing and analysis of expansive soils under PCC pavements, developed in this report, were adopted as a standard method of test in April 1965. A copy of Test Method No. Calif. 354B, entitled "Method of Test for Evaluating the Expansive Potential of Soils Underlying Portland Cement Concrete Pavements" is included as Appendix B.

DISCUSSION

<u>Relationship of Moisture and Density to Expansion of Soils</u>:

In accordance with the usual academic approach to the behavior of expansive soils, it is axiomatic that potential swell of a given soil is a function of the density as well as the moisture content. In general, soils compacted to high density will possess a capacity for expansion greater than those of lower density. This is due largely to the increase in "osmotic repulsive pressure" (pressure developed by electrical repulsion between clay particles), consequent to decreased interparticle spacing (10), and the fact that there are more interacting soil particles, per unit volume, contributing to expansion.

From the practical standpoint, however, expansiveness is not affected significantly by density within the normal range achieved during construction. Figure 1 demonstrates, by an example involving tests on a heavy clay, the manner in which expansiveness varies with densities over a broad range of moisture contents. The plotted points in the chart represent individual test specimens and the expansion pressures, as determined by using various compaction pressures in the standard R-value test (6), are noted beside each point. By interpolation, the heavy dashed lines are fitted as isobars (lines of constant pressure) and labeled according to the expansion pressure represented. Also included is the moisture-density curve, as determined by the California Impact Compaction Test (7), and the corresponding levels of 95% and 90% relative compaction. It is evident from this figure that in the region of optimum moisture, above the limiting values of relative compaction, the expansion pressures vary but little with changes in density. On the other hand, it is apparent that expansion pressure is quite sensitive to changes in compaction moisture. Similar relationships have been found by W. G. Holtz and H. J. Gibbs (8) in tests involving volumetric expansion, as shown in Figure 2.

From the above it is clearly evident that effective control of expansive soils under PCC pavements must be achieved primarily by controlling placement moisture. Densities within the scope of normal construction operations are not significant.

Relationship of Expansion Pressure to Volume Change:

The method of analysis of expansive soils under PCC pavements, as outlined in the 1954 circular letter (5), is based upon expansion pressure determinations performed in the manner of the standard R-value test procedure (6). This data is analyzed by using a table of allowable expansion pressures which are arranged according to depth below the top of the pavement. The weight of cover required to restrain expansion and establish the minimum moisture level which must be met in construction is thus determined for a given soil.

The use of expansion pressure measurements for this purpose appears logical when one considers the design problem purely from the aspect of the forces generated by traffic on the roadbed. However, the curling of PCC pavement, caused by expansive soils, is physically a direct result of volume change in the underlying soils and should actually be evaluated on that basis. Laboratory studies indicate that in many cases there is no direct relationship between expansion pressure and volume change.

It has been found that materials containing significant amounts of silt have a tendency to exhibit higher expansion pressures than might be predicted from volume change measurements. To illustrate this, a series of test samples from various parts of the State have been arranged in Table I in four groups according to this respective soil classification.

The test values for linear expansion and expansion pressure in psi are shown opposite each sample. The average test values from this table, for each soil group, are then plotted in Figure 3 and the points connected with solid straight lines. Also shown is the range of linear expansion for each soil group. If the two variables (Linear expansion and expansion pressure) were proportional, then the three "silt groups" should fall along the dashed straight line. This, however, is not the case since all three silty materials indicate average expansion pressures well above the theoretical line. Those examples demonstrate the tendency to overrate the expansive capacity of these soil types in comparison to the highly expansive clays. There is, therefore, a generally poor correlation exhibited between expansion pressure and volume change as determined by the linear expansion test and is illustrated in Figure 4.

In the final analysis, however, it is necessary for a test to permit a liberal amount of volume change in its performance in order to effectively evaluate the potential of this variable. Unfortunately, insignificant volume change takes place in the standard expansion pressure test and high pressures are sometimes developed which would be considerably relieved if more volumetric swell were permitted.

At this juncture, it should be pointed out that the expansion pressure test, as applied in the R-value method (6) for the design of bituminous structural sections, has proved to be quite effective. In the case of bituminous sections, the primary concern is the weight (or pressure) of cover (and consequently thickness) necessary to restrain expansion within safe levels of stability (R-values). There is no need to evaluate potential volume change or linear movement in this instance. Expansive soil under PCC pavements is of prime concern when expansion can occur differentially.

THE DEVELOPMENT OF A CRITERION TO SAFEGUARD AGAINST CURLING

Of the six major projects exhibiting serious PCC curl, as listed in the introduction to this report, only the Warm Springs project (No. 5) provides sufficient data to form the basis of a test for analyzing future projects. Unfortunately a single project does not offer the variety of soil types to provide the certainty that a given test will be generally applicable to all clay minerals. This difficulty, however, is minimized in the study by a scheme which involves three major subdivisions of both laboratory and analytical work.

First the linear expansion test, which is described in Appendix A, was applied to soils from the Warm Springs project. The purpose of this was to establish a relationship between volumetric expansion, as determined by laboratory test,

TABLE I

Tabulation of Linear Expansion and Expansion Pressure Test Data on Statewide Samples Grouped According to Soil Classification

NOTE: All Tests Performed at Optimum Moisture by Kneading Compaction

Sandy Silts & Silts			Clayey Silt			Silty Clay			Clay		
Dist. Co.	Linear Exp. (%)	Exp. Pr. (psi)	Dist. Co.	Linear Exp. (%)	Exp. Pr. (psi)	Dist. Co.	Linear Exp. (%)	Exp. Pr. (psi)	Dist. Co.	Linear Exp. (%)	Exp. Pr. (psi)
03-Gle	0.03	1.50	03-Gle	0.2	1.20	03-Yol	0.8	3.61	10-Sol	3.7	6.92
11-SD	0.1	0.15	03-Gle	0.6	1.80	03-Gle	0.8	1.80	10-Sol	4.0	4.36
11-SD	0.2	1.28	04-SCl	0.6	1.88	03-Yol	0.8	3.99	10-Sol	4.1	8.05
11-SD	0.2	1.58	11-SD	0.7	2.93	03-Gle	0.9	4.14	10-Sol	4.2	6.84
03-Yol	0.2	1.65	03-Yol	0.8	3.76	05-SB	0.9	2.41	03-Yol	4.3	8.12
03-Yol	0.2	1.20	11-SD	0.8	4.51	10-Sol	1.2	1.88	03-Gle	4.3	8.42
03-Yol	0.2	1.35	11-SD	1.0	3.68	03-Yol	1.2	2.71	03-Yol	4.5	7.75
03-Yol	0.3	2.18	05-Mon	1.1	3.38	03-Yol	1.3	3.91	03-Yol	4.8	6.39
11-SD	0.3	1.96	04-SCl	1.1	2.11	04-SCl	1.3	4.51	03-Yol	5.2	9.25
11-SD	0.3	1.80	03-Sac	1.2	7.14	05-SB	1.3	2.11	10-Sol	5.2	6.09
03-Yol	0.4	2.71	05-SB	1.3	3.46	11-SD	1.5	7.97	10-Sol	6.0	9.63
11-SD	0.5	1.65	11-SD	1.3	4.36	05-SB	1.6	3.01	05-Mon	6.8	11.43
03-Yol	0.5	2.71	05-Mon	1.4	3.61	03-Sac	1.7	5.72	10-Sol	7.5	10.23
			10-Sol	1.8	5.26	05-Mon	1.8	3.99	02-Teh	7.4	8.30
			05-SLO	2.3	7.97	05-Mon	1.9	3.91	02-Teh	7.4	12.00
			10-Sol	2.3	7.52	10-Sol	2.0	4.59	03-Yol	7.6	9.78
						11-SD	2.2	8.80			
						10-Sol	2.2	2.63			
						10-Sol	2.3	3.76			
						05-SB	2.5	4.21			
						04-SCl	2.6	6.39			
						03-Yol	2.7	6.02			
						05-SB	2.9	7.14			
						10-Sol	3.5	9.63			
						05-Mon	3.5	3.61			
						10-Sol	3.7	7.90			
						04-SCl	3.9	9.02			
						02-Teh	3.9	5.32			
						10-Sol	4.7	9.02			
No.	13	13.	No.	16	16	No.	29	29	No.	16	16
Average	0.3	1.65	Average	1.2	4.06	Average	2.1	4.96	Average	5.4	8.35

and the pavement curl phenomena on the project. From an analysis of data, it was then possible to determine a series of allowable linear expansion values for various thicknesses of cover.

The second phase of the program involved the development of a rapid practical test, for general routine use, which would effectively reflect the volume change characteristics of soils. Unfortunately, the linear expansion test is not suitable for application to design or construction control due to the excessive length of time it takes (up to 70 days) to attain the end point measurement. As a result, considerable effort has been extended in seeking a faster test that could be effectively applied by our district materials departments. A modification of the present standard expansion pressure test appears to be the most feasible of the various methods tried. It is called the "third cycle" expansion pressure test. Briefly, this test consists of placing standard test specimens, 4-in. diameter 2½ in. high, in the E.P. device in the normal manner, with a 0.33 ft. cover surcharge applied. The specimen is allowed to expand overnight with water available only at the top. The following day the expansion pressure is read and released back to the starting point (zero on the dial) and the specimen allowed to expand for the second time overnight. The process is repeated by reading and releasing the E.P. built up during the next day and for the third and final time permitting expansion overnight. The expansion pressure reading on the third day (cycle), after an elapsed time of 16 to 24 hours from the final setting, is taken as the primary test value and is recorded for use. Details of the procedure are found in Appendix B.

One of the principal advantages of this "third cycle" test, over the standard (one cycle) expansion pressure test, is the manner in which it improves the discrimination between the relatively low-volume-change silty materials and the high-volume-change clays. The fact that some volume change is permitted in the specimen, during the test, apparently makes this possible. The improvement is demonstrated by analyzing a series of third cycle expansion pressure test results, with respect to "statewide" samples arranged in soil classification groups, in exactly the same manner as previously illustrated for standard (1 cycle) expansion pressures in Figure 3. The comparable analysis of the third cycle expansion pressure results is thus shown in Figure 8. It is noted that there is still a slight tendency for silty materials to fall above the theoretical line. However, it is believed that the trend is sufficiently minimized as to render the third cycle E.P. test satisfactory for application to the PCC curl problem (compare Figure 8 with Figure 3).

The third and final phase of the study concerned the determination of the relationship of the third cycle expansion pressure test with linear expansion. Numerous samples of expansive soil, representing many clay mineral types, were obtained from various parts of the State. Both the third cycle and linear expansion tests were performed on these samples and a suitable correlation was established between the two tests. Then, through the application of the previously determined allowable linear expansion values, a set of allowable third cycle expansion pressures were developed. These latter values form the fundamental basis for the method of application to design and control, which will be described later in this report.

TESTING PROGRAM AND ANALYSIS OF DATA

In the original report (September 1954) on the investigation of the Warm Springs project (3), it was clearly indicated that the difficulty originated in the embankment material. This material was obtained from three sources under two contracts (52-4TC22 and 53-4TC23-F). The top of the embankment material in all cases is a nominal 20 inches below profile grade. Figure 5 illustrates the "profile" structural section along with details regarding the areas exhibiting curl, limits of embankment sources, etc. It is noted that the curling occurred generally in the northerly portion of the road (Contract 53-4TC23-F) where material obtained from the excavation for a railroad underpass was used for embankment. In the original report (September 1954) it was indicated that the railroad excavation material (RR excav.) ended at Station E48+00 which would leave the curled joint at Station E40+05 in the area where imported borrow from the Curtner Pit was used. However, subsequent information and analysis of test samples indicates that the embankment is a mixture from both sources between approximate Stations E30 and E48 with the RR excavation material predominating (Figure 5). Available information indicates that the embankment was subject to considerable drying, due to an extended hot dry period, prior to completion of the road. In any event, the moisture samples obtained at midslab in the original investigation, as shown in Table II, probably more nearly indicate the true moisture condition.

TABLE II
Midslab Inplace Moisture Contents Embankment Material
(Warm Springs Project)

Station	% Moisture	Source
E 80+98.5	10.4	RR Excavation
E 70+47.5	10.5	RR Excavation
E 40+12.5	13.8	RR Excavation & Curtner Pit Mixture
A310+93.5	15.3	Curtner Pit
A121+77.5	12.5	Winterbaur Pit

Undoubtedly, even the above moisture values are somewhat higher than the starting values due to the natural increase from ground water sources during the six months of winter weather which intervened between slab placement and moisture sampling.

Therefore, based upon available information, it is estimated that the average moisture level of the embankment at the time of slab placement on the respective two contracts is as follows:

53-4TC23-F - (Curled & Normal Joints) - 10%

52-4TC22 - (Normal Joints) - 12%

These moisture contents are utilized in the following linear expansion analysis of the embankment material from the Warm Springs project.

Samples of embankment material were obtained from various locations beneath both the curled and normal (uncurled) portions of the Warm Springs project, as indicated in Figure 5. In addition to the samples taken from the road in the original investigation (September 1954), it was necessary to perform two subsequent samplings, in 1958 and 1959 respectively, in order to have sufficient material for the complete testing program.

The Linear Expansion Test Series:

The linear expansion test specimens fabricated in this series were tested under varying conditions of surcharge and compaction moisture contents. The surcharges used expressed in equivalent thicknesses of cover (assumed to weigh 130 lbs/cu. ft.), ranged from 12 inches to 72 inches of cover. In general, moisture contents, for a group of approximately four specimens representing each sample, were arranged to extend from about 9% up to levels of 16 or 20%.

Upon completion of the tests, moisture-linear expansion curves were plotted for each condition of surcharge and the linear expansion values at the presumed construction moistures (10 or 12% as explained previously) were interpolated from the respective curves. These interpolated values are shown in Table III along with other pertinent sample data.

A plot of the linear expansion values against surcharge cover, for samples taken from areas of curled and normal joints respectively, is shown in Figure 6. It is noted that the points form a pattern with the material from the curled and normal joints falling in two well separated groups that do not overlap. A curved line has been interpolated and drawn to represent a "reasonable" dividing line between the materials that cause curling and those that do not. The line also serves to illustrate the typical reduction in linear expansion which results from increasing weight of cover.

TABLE III

Tabulation of Linear Expansion Values Determined on Embankment Material From the Gish Road to Warm Springs Project

04-SC1, Ala-69-A,E

Contracts 52-4TC22 & 53-4TC23-F

Station	Lane	Depth (in.)	Material	Joint Condition	Test No.	Moisture at Compaction (%)	% Linear Expansion at 70 Days Surcharge (Equiv. in inches of cover) 12"	20"	24"	36"	48"	72"
E 80+98.5	SB	22-32	RR Exc	Curled	54-1610	10%	-	5.8	-	-	-	-
E 80+91	SB	22-30	" "	"	54-1607	"	-	6.1	-	-	-	-
E 76+23	SB	18-28	" "	"	58-760	"	6.6	-	5.6	4.8	3.5	2.6
E 70+55	SB	21-32	" "	"	54-1604	"	-	6.8	-	-	-	-
E 70+55	SB	21-34	" "	"	59-1218	"	6.1	-	5.5	4.5	4.5	-
E 70+47.5	SB	20-32	" "	"	54-1601	"	-	8.7	-	-	-	-
E 61+70	NB	18-30	" "	"	59-1215	"	6.9	-	4.8	4.2	3.8	-
E 61+38	SB	22-32	" "	"	58-762	"	-	-	5.0	4.1	3.3	3.3
E 57+76	SB	19-27	" "	"	58-767	"	8.4	-	7.0	-	6.1	4.8
E 57+61	SB	20-28	" "	"	58-764	"	7.1	-	5.9	5.8	4.5	3.6
E 40+05	SB	18-32	RR Exc & IB Curtner Pit	"	59-1220	"	9.0	-	8.1	7.5	7.0	-
E 26+70	SB	16-31	Curtner Pit	Normal	59-1222	10%	2.0	-	1.8	1.5	0.8	-
A311+08.5	NB	18-23	"	"	58-772	"	1.3	-	1.0	1.0	0.9	0.4
A311+08.5	NB	23-28	"	"	58-773	"	2.2	-	1.9	1.7	1.4	1.0
A310+93.5	NB	23-34	"	"	54-1613	"	-	3.5	-	-	-	-
A310+86	NB	22-33	"	"	59-1229	"	1.8	-	1.4	1.3	1.2	-
A250+00	SB	21-31	"	"	59-1224	"	2.1	-	1.6	1.4	1.1	-
A121+77.5	NB	21-30	Winterbauer	"	54-1619	12%	-	1.9	-	-	-	-
A120+70	NB	21-26	"	"	59-1226	"	1.6	-	1.4	1.0	0.8	-
A120+70	NB	26-34	"	"	59-1227	"	0.2	-	0.1	0.0	-	-

With this relationship established, it is now possible to develop a series of allowable values for linear expansion at various depths. This is accomplished in Figure 7 by first replotting the previous curve (shown as intermittent short and long dashes). Since the top of the embankment material was actually placed at a nominal 20" below profile grade, the ordinate value of linear expansion of 4% noted at this depth, is the "critical value" for the road. As previously mentioned, the curve shows the resistance to linear expansion which results from added cover load. This means that an allowance can be added to the critical value, for depths greater than 20", in the amount that the linear expansion is reduced below 4%. For example, supposing it is desired to determine the critical value for a depth of 36" below the top of the pavement. It can be seen that the added surcharge of 16" (36" - 20") reduces the linear expansion by 1.1%. Therefore, this means that at the 36" depth, the permissible linear expansion can be increased by 1.1% over the allowance of 4.0% at 20", or a total of 5.1% allowable for 36". The reverse is also true for depths less than 20". In Figure 7, the above process is repeated for each 6" of thickness between 12" and 48" depths and a curve is drawn connecting the coordinates. This becomes the allowable linear expansion curve and Table IV lists the allowable values for various depths.

TABLE IV

Allowable Linear Expansion Values

Depth Below Profile Grade	Potential Linear Expansion
12"	3.2%
18"	3.8
24"	4.3
30"	4.7
36"	5.1
42"	5.4
48"	5.7

The Third Cycle Expansion Pressure Test Series:

The next step in the study involved the determination of a suitable relationship between third cycle expansion pressure and linear expansion. Table V displays test data on samples taken from various projects in the State where expansive soils have been encountered. In this group of tests the linear expansion was determined for both 24" and 48" depth of surcharge.

TABLE V

Comparison of Third Cycle Expansion Pressure With Linear Expansion On Soil Samples Obtained From Various Locations in the State

Tests Performed at Optimum Moisture by Kneading Compaction

Project Sampled Dist-Co-Rt-Sec.	Test No.	% Linear Expansion 24" Surcharge	% Linear Expansion 48" Surcharge	Third Cycle Expansion Press. (PSI)
02-Teh-3-C	60-677A	3.9	3.2	3.0
	678A	7.4	5.5	6.60
	679A	6.9	5.0	5.85
	680A	7.4	6.2	6.16
03-Gle-7, 47-B,C,A	59-937	0.8	0.2	0.98
	938	0.9	0.4	1.80
	940	0.2	0.1	0.53
	941	4.3	3.4	4.81
	942	0.6	0.2	0.90
03-Sac-4-Sac	59-1881	1.7	0.9	1.73
03-Yol-6-A	60-572	5.2	4.4	5.11
	573	1.2	0.9	1.20
	574	3.6	2.1	3.01
03-Yol-90-B	59-1531	4.5	3.8	4.81
	1532	2.7	2.2	3.23
	1533	4.8	3.2	4.44
	1534	7.6	5.8	6.39
04-SCl, Ala-69 A,E	59-1215	2.6	2.0	2.63
	1218	1.3	1.1	1.20
	1220	3.9	2.9	4.51
	1222	0.8	0.5	1.35
	1224	1.1	0.7	0.75
	1226	0.9	0.4	1.13
	1227	0.1	0.0	0.15
	1229	0.6	0.1	0.83
05-Mon-56-Mon	58-1933	1.8	1.2	2.93
	1935	1.9	1.3	3.24
05-SB-2-P,Q	59-621	2.5	1.2	2.56
	622	1.3	1.0	2.11
05-SB-2-SB	60-522	1.3	0.8	1.35
05-SBt-2-Q,G	60-855	2.8	2.3	3.46
10-Sol-7-C	59-1299	3.5	2.7	5.04
	1300	2.0	1.7	2.11
	1301	2.3	2.2	2.48
	1302	4.2	3.6	4.06
	1303	4.1	3.2	3.91
	1304	1.2	0.7	0.83
	1305	2.2	1.7	2.11
	1306	3.7	2.9	4.36
10-Sol-7-D	59-1965	6.0	4.8	5.64
	1966	1.8	1.5	2.11
	1967	4.7	4.0	4.81
11-SD-2-SD	59-857	0.3	0.2	0.75
	858	1.3	0.6	1.96
	58-2178	0.8	0.6	1.73
	2179	1.0	0.6	1.35
	2182	0.3	0.3	0.45
	59-529	0.1	0.1	0.15

All test specimens for the series were fabricated by the kneading compactor at moisture contents providing maximum density in the respective materials. The resulting moisture-density conditions developed in the specimens are considered to be analogous to typical conditions prevailing in construction and, therefore, are used for the purposes of this study.

Figures 9 and 10 are plots of data from Table V showing linear expansion with 24" and 48" surcharge. As a matter of interest, compare Figure 9 with the previous Figure 4. It is noted that dispersion is greatly minimized and the data falls into a definite pattern when third cycle expansion pressures are used in lieu of the standard 1 cycle test (Figure 4).

A line is drawn on each chart (Figures 9 and 10) which just skirts the lowest third cycle expansion pressure values. These lines represent the maximum limiting linear expansion values which could be expected for given values of third cycle expansion pressure and form the basis for determining the allowable values.

The "limiting" lines for the 24" and 48" surcharges are redrawn in Figure 11. Unfortunately, time and equipment limitations did not permit the determination of linear expansion for other surcharges. However, the lines for 12, 18, 30, 36 and 42 inches were reproduced with the aid of the curve shown in Figure 6. This is possible because, as previously stated the curve (Figure 6) represents the change in linear expansion which results from change in cover thickness. An example of how this is accomplished is given, as follows, for the 36" surcharge:

> The vertical distance between the 24" and 48" surcharge lines is measured with a rule at some convenient location (Figure 11). In this case the vertical distance along the 6% linear expansion ordinate was selected and found to measure 1.1". Referring to Figure 6, it is found that the linear expansion decreases between 24" and 48" by 3.7 - 2.3 = 1.4%. Also between 24" and 36" the decrease is 0.8%. Therefore, by proportioning, the distance up from the 24" line to the 36" line in Figure 11 is calculated:
>
> $$\frac{0.8\%}{1.4\%} \times 1.1'' = 0.63''$$
>
> This distance is laid off vertically from the 24" line and then the 36" surcharge is drawn to the origin. The other surcharge lines are determined in a similar manner.

The final step in this analysis consists of establishing the allowable third cycle expansion pressure values for various depths below profile grade. This is accomplished by entering the Abscissa of the chart in Figure 11 with the allowable linear expansion values, listed in Table IV, and intersecting the respective surcharge lines corresponding to the depths associated with each linear expansion value. The maximum allowable third cycle expansion pressure values, as read from the ordinate at the intersection points, are indicated in Table VI.

TABLE VI

Maximum Allowable Third Cycle Expansion Pressure Values

Depth Below Profile Grade (Inches)	Lbs. Per Sq. In.
12	1.88
18	2.52
24	3.16
30	3.70
36	4.28
42	4.74
48	5.25

One final comment should be made at this time regarding the "effective depth" of expansion, before undertaking an explanation of how the allowable third cycle expansion pressures are applied to design and construction. It is believed that the expansiveness of soil insofar as it causes curling in PCC slabs is not effective below the depth of 4 feet in the roadbed. The passage of surface water, through a structural section greater than 48 inches in thickness, would normally become so dispersed by the time it reached the expansive material that little if any differential swell could develop. Therefore, the values given in Table VI are carried only to a depth of 48" below profile grade.

APPLICATION

The application of the measured third day expansion pressures to both design and construction is somewhat similar to the method outlined in the 1954 Circular Letter (5). However, modifications of the test procedure and certain innovations in the analysis warrant elaboration of the entire method.

The first step is to obtain representative samples from the roadbed soils and possible pit sources. Sampling should delineate, as nearly as possible, the areas of high swell potential. The validity of the entire analysis will be largely dependent upon the care with which samples are selected.

The standard R-value (Test Method No. Calif. 301 with minor modifications), and the third cycle expansion pressure test (Appendix B) are performed as individual test sets. Both sets should contain from 4 to 8 specimens which range in moisture content from values straddling the compactor air pressure drop, to those which reduce third cycle expansion pressures to negligible amounts. The individual test specimen R-values and third cycle expansion pressure values, obtained from the respective test sets, are then utilized in the analysis of the PCC curl potential of the soil. The details of the third cycle EP procedure along with the modifications required in the standard R-value test may be found in the test method attached as Appendix B.

Design Analysis

The third cycle expansion pressure and R-value test data should be plotted as shown in the example given in Figure 12. Referring to the allowable third cycle expansion pressures given in Table VI, enter the chart from the left hand scale with various allowable pressures. Determine, from the intersection with the EP curve, the moisture content required to maintain expansion within the allowable pressures.

At this point the maximum moisture level which can be attained in construction and still maintain workability or firmness of the working table to permit construction operations, will be the primary factor determining the minimum thickness of structural section required. Experience has indicated that in order to hold expansion within allowable limits and obtain the most economical section in design, it is invariably necessary to maintain moisture levels on the wet side of optimum during construction. Therefore, as a guide to the designer in exercising his judgment in this matter, the following criteria are suggested:

1. If the interpolated R-value, at the moisture content under consideration, is in the vicinity of 30 or less, then in most cases the soil is reaching a point where the stability is sensitive to a slight increase in moisture content.

2. A rough estimate can also be made of the critical compaction moisture value by noting the moisture content at which the air pressure on the mechanical compactor (and consequently the foot pressure) must be lowered due to excessive penetration of the foot into the specimen.

3. Experience has shown that soils, when compacted at moisture contents which give R-values of 10 or less, are unstable and will not support construction equipment. As a margin of safety, a moisture content at 10 R-value minus 4% should enable construction equipment to operate satisfactorily.

When expansive soils are encountered during preliminary sampling on a project, where concrete pavement is contemplated, the swell potential should be discussed fully in the Materials Report so that construction procedures may take them into account. This includes the listing of the minimum moisture contents required to attain the allowable third cycle expansion pressure corresponding to the proposed structural thickness. It is further suggested that copies of charts, drawn for the purpose of analysis in the manner of Figure 12, should also be included in the materials report as an aid to reviewers.

In general, the new criteria employing the third cycle expansion pressure test, requires less cover than the 1954 method (5). The example shown in Figure 12 was taken from actual tests in which the 1954 criteria required 48" of cover. Incidentally, soil classification of this sample identifies it as a silty clay. A review of the limited number of third cycle expansion pressure tests which have been performed to date, demonstrates the overall reduction in cover requirements as shown in Table VII.

It is noted that while the trend is toward thinner sections by the third cycle EP method, there are still some soils which require the full 48" of cover. These materials are high volume change types and their use in the effective zone (upper 48") of the roadbed must be avoided if the risk of pavement curl is to be minimized.

Construction Control

Good control during construction is essential where expansive soils are encountered. Minimum moisture levels must be reached and maintained in the expansive material during construction.

Expansive clay soils are characteristically very critical as to moisture content. An example of this can be seen in Figure 12 where 24.8% moisture is the minimum level for 24" of cover. If the moisture is reduced 2% to 22.8%, then 36" of cover would be required to restrain the soil at this drier state. This emphasizes the importance of taking steps during construction to assure that the minimum moisture content established in the design is actually present in the underlying soil at the time the pavement is constructed.

With respect to the depth at which the moisture must be maintained, it is felt that the mixing of water with soil to a depth of 4' below profile grade, as required by the 1954 method (5), is excessive. Experience with heavy clays indicates that moisture penetration is very slow when the soil is well compacted and under a surcharge weight of cover. It normally takes about 70 days in the linear expansion test for moisture to penetrate a little over one inch in a clay soil test specimen. Since marked curling in PCC slabs has in the past generally occurred within one year after construction, the

TABLE VII

Comparison of the Third Cycle Expansion Pressure Method with The 1954 Method in Terms of the Proportion of Samples Categorized According to Cover Requirements

Cover Required by Method Outlined in E. Withycombe's Letter Dated 10/29/54 (inches)	Cover Required by Third Cycle Expansion Pressure Method (inches)	No. of Samples	% of Total Samples
48	48	13	25
48	42	2	4
48	36	9	17
48	30	8	15
48	24	17	33
48	18	3	6
	Sub Total	52	100
36	36	0	0
36	30	0	0
36	24	7	41
36	18	7	41
36	12	3	18
	Sub Total	17	100
24	24	0	0
24	18	2	100
	Sub Total	2	100

swell must largely originate in the top one foot of the expansive layer. It must also be realized that the intruding surface water will move laterally through any pervious subbase layer which in turn will tend to equalize the swell under the slab. This means that, if serious curling has not occurred in the first year or so, the moisture will tend to be uniformly distributed and localized expansion unlikely to occur. Other factors such as capillarity, the evaporation-condensation phenomena, etc., are also aiding the equalization of moisture during this time. It is, therefore, believed that maintenance of the proper moisture level during construction is necessary only for the top one foot of the expansive material.

After construction starts, sack samples (control samples) should be obtained at various locations along the road, particularly in areas where the heaviest clays are found, and forwarded to the district laboratory for the third cycle expansion analysis. In addition to reporting the usual test data (Form T-375), for each control sample, the District Materials Department should also include, under remarks, both the optimum moisture content and the minimum allowable moisture for the planned structural section. Some instances may occur where materials in localized areas are encountered which are more highly expansive (and consequently require, for the given design an excessive amount of water) than those upon which the design is based. In these cases, it is usually the best practice to make provision to replace the material, usually to a depth of 4' below profile grade, with imported material which is relatively non-expansive.

It is realized that subgrade moisture control on a going PCC project, particularly at the higher moisture levels required for expansive soils, can be quite difficult. Experience indicates that there are several means which can be employed by the resident engineer to help facilitate the task.

First is the development of a "soil moisture profile" using the available test data. This consists of plotting the following items to a convenient scale on standard cross section paper with road stationing arranged horizontally and percent moisture shown vertically:

1. Minimum allowable moisture from the third cycle expansion analysis.

2. Optimum moisture as determined from the impact compaction test.

3. Initial moisture content of the soil at the start of watering and compaction operations.

The plotted points for the above data are connected with straight lines (different colors can be used for easy identification) as illustrated by the example in Figure 13. This profile presents an easy means of visualizing the moisture situation for the project as a whole and also reveals critical areas which may require extra attention. As watering is undertaken, inplace moisture samples should be obtained at regular intervals and the test data superimposed on the chart for "up-to-date" information on the progress of application.

Another suggestion is to start a regular schedule of daily watering operations at least a week in advance of compaction, if possible. Clay materials normally do not absorb water readily and will become highly plastic if too much water is introduced at one time. Slow elevation of the moisture content in the upper foot of the expansive layer through advanced watering is particularly advantageous during the dry season when the starting or initial moisture level of the soil is low.

The practice of advanced watering has been recommended and utilized by the California Division of Highways, on several occasions in the past. Other State Highway Departments have also been known to undertake "pre-wetting" successfully, especially in the State of Wyoming (9). While our previous efforts were directed towards elevating the moisture levels in the roadbed to facilitate compaction, there appears to be no reason why the same principles could not be applied to the expansive soil problem.

As a final comment, with regard to construction control, it should be emphasized that it is <u>very essential</u> to maintain the proper moisture level in the <u>soil until the</u> cement treated base has been placed. This means that watering must continue after the subbase layer has been placed. Experience has indicated that the expansive soil <u>must not be permitted to dry out</u> as this can be more serious than not attaining the proper moisture level initially. Failure to observe this precaution is believed to have been the primary cause of the curling evidenced on the Warm Springs project.

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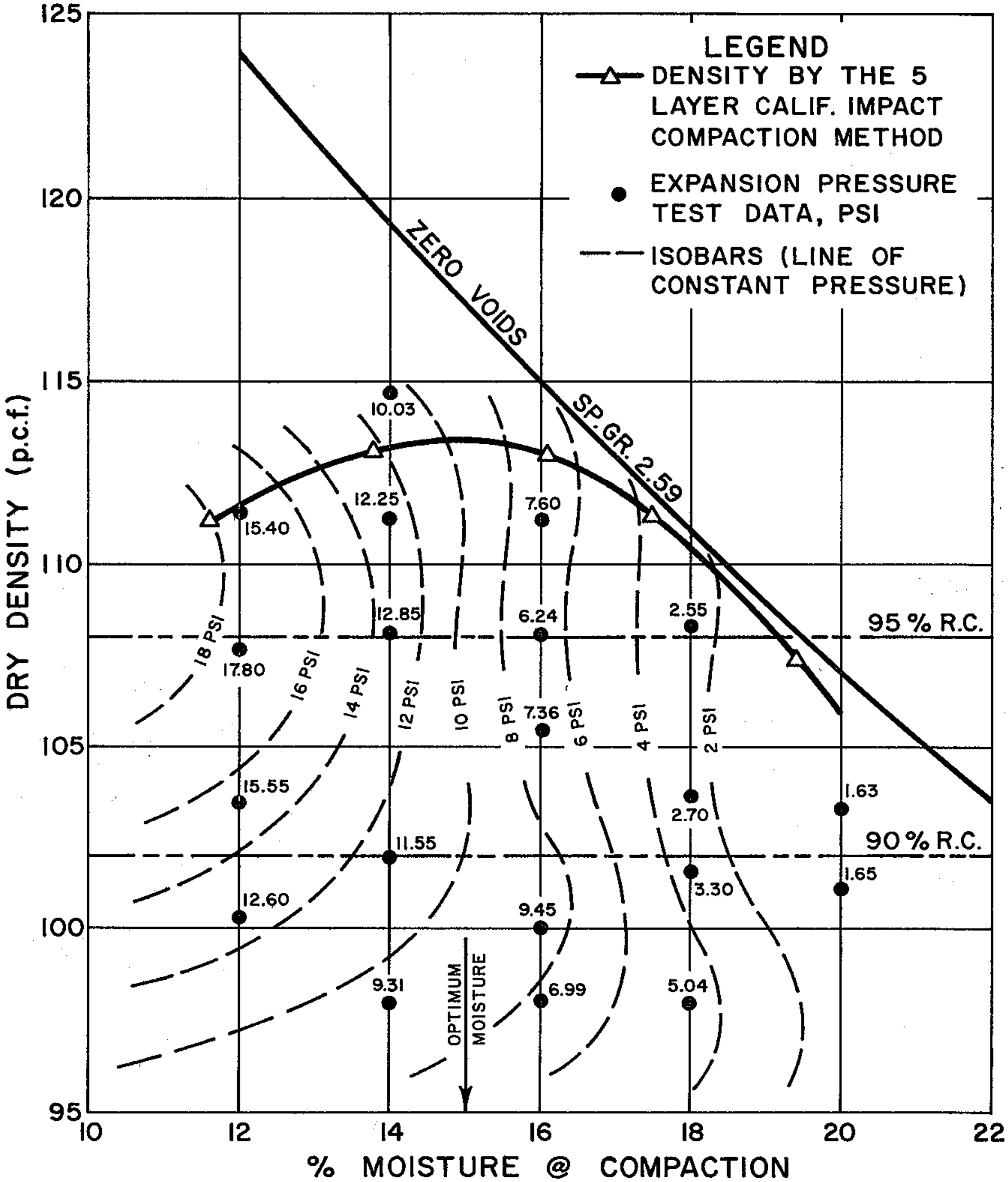
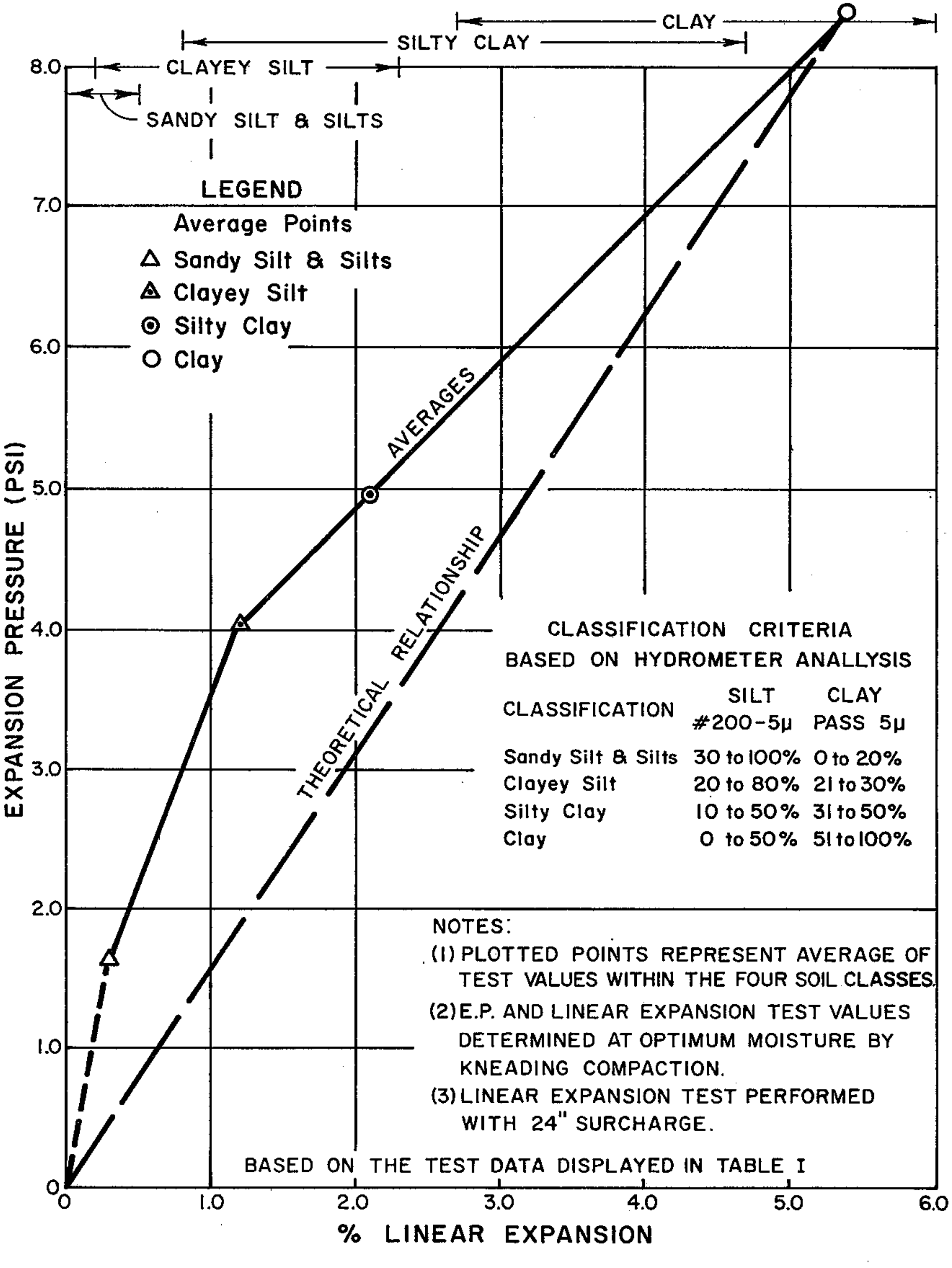
THE RELATIONSHIP OF EXPANSION PRESSURE TO VARIOUS CONDITIONS OF COMPACTION MOISTURE AND DENSITY TEST NO. 59-1638



PLOT ILLUSTRATING TENDENCY OF EXPANSION PRESSURE TO DEVIATE FROM THEORETICAL RELATIONSHIP WITH VOLUME CHANGE



CLASSIFICATION CRITERIA
BASED ON HYDROMETER ANALLYSIS

CLASSIFICATION	SILT #200–5μ	CLAY PASS 5μ
Sandy Silt & Silts	30 to 100%	0 to 20%
Clayey Silt	20 to 80%	21 to 30%
Silty Clay	10 to 50%	31 to 50%
Clay	0 to 50%	51 to 100%

NOTES:

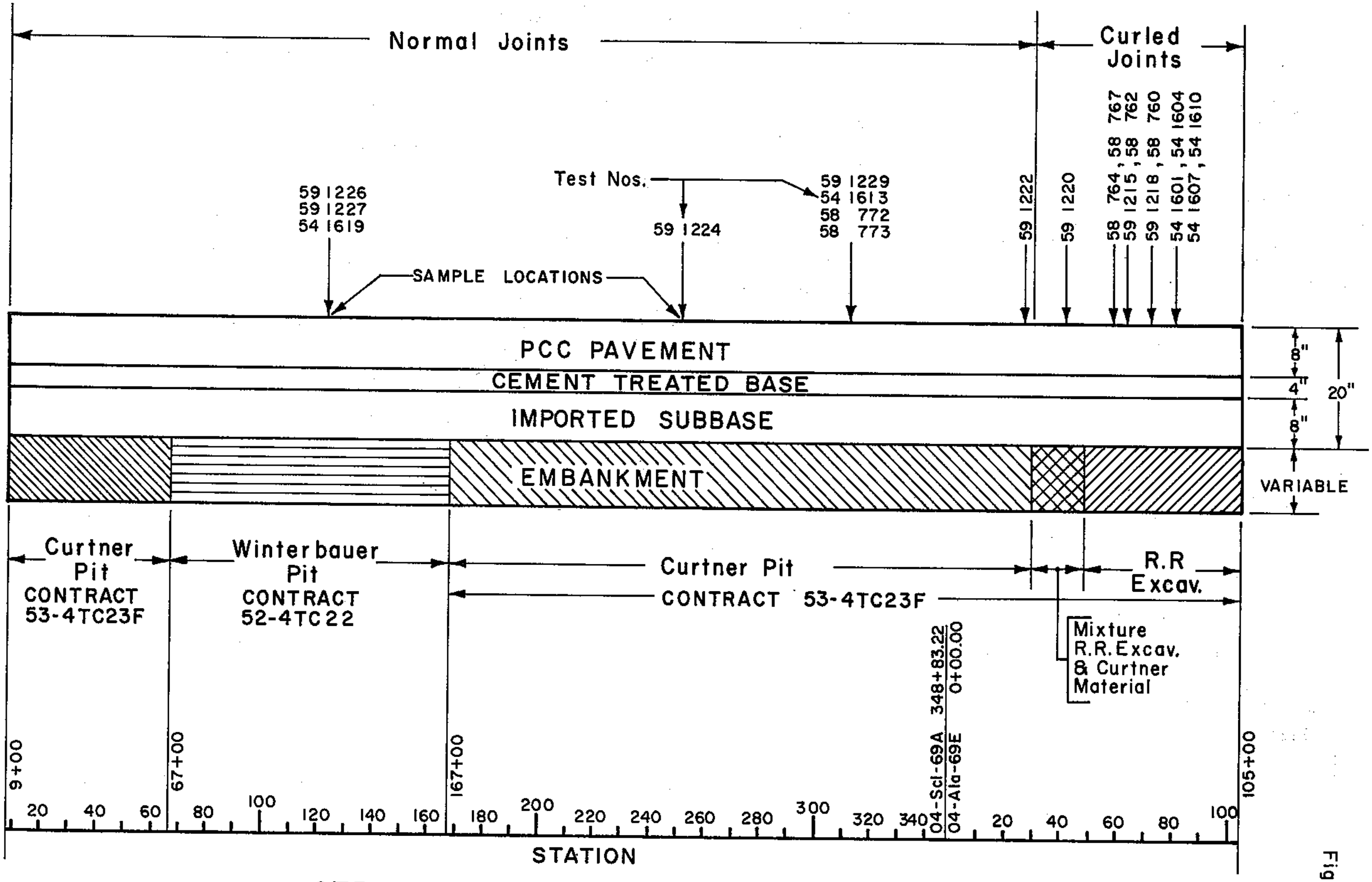
(1) PLOTTED POINTS REPRESENT AVERAGE OF TEST VALUES WITHIN THE FOUR SOIL CLASSES.

(2) E.P. AND LINEAR EXPANSION TEST VALUES DETERMINED AT OPTIMUM MOISTURE BY KNEADING COMPACTION.

(3) LINEAR EXPANSION TEST PERFORMED WITH 24" SURCHARGE.

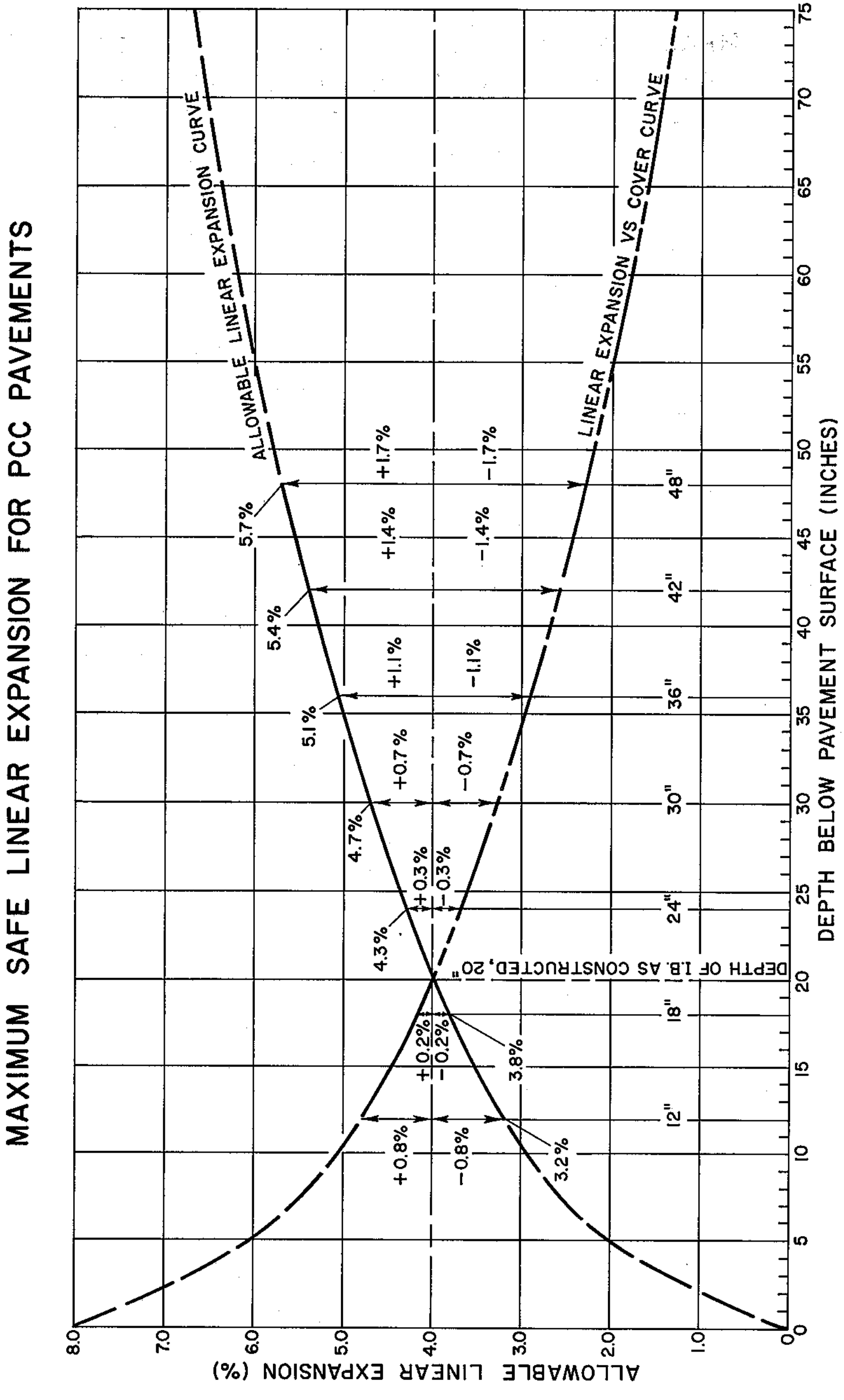
BASED ON THE TEST DATA DISPLAYED IN TABLE I

Figure 5



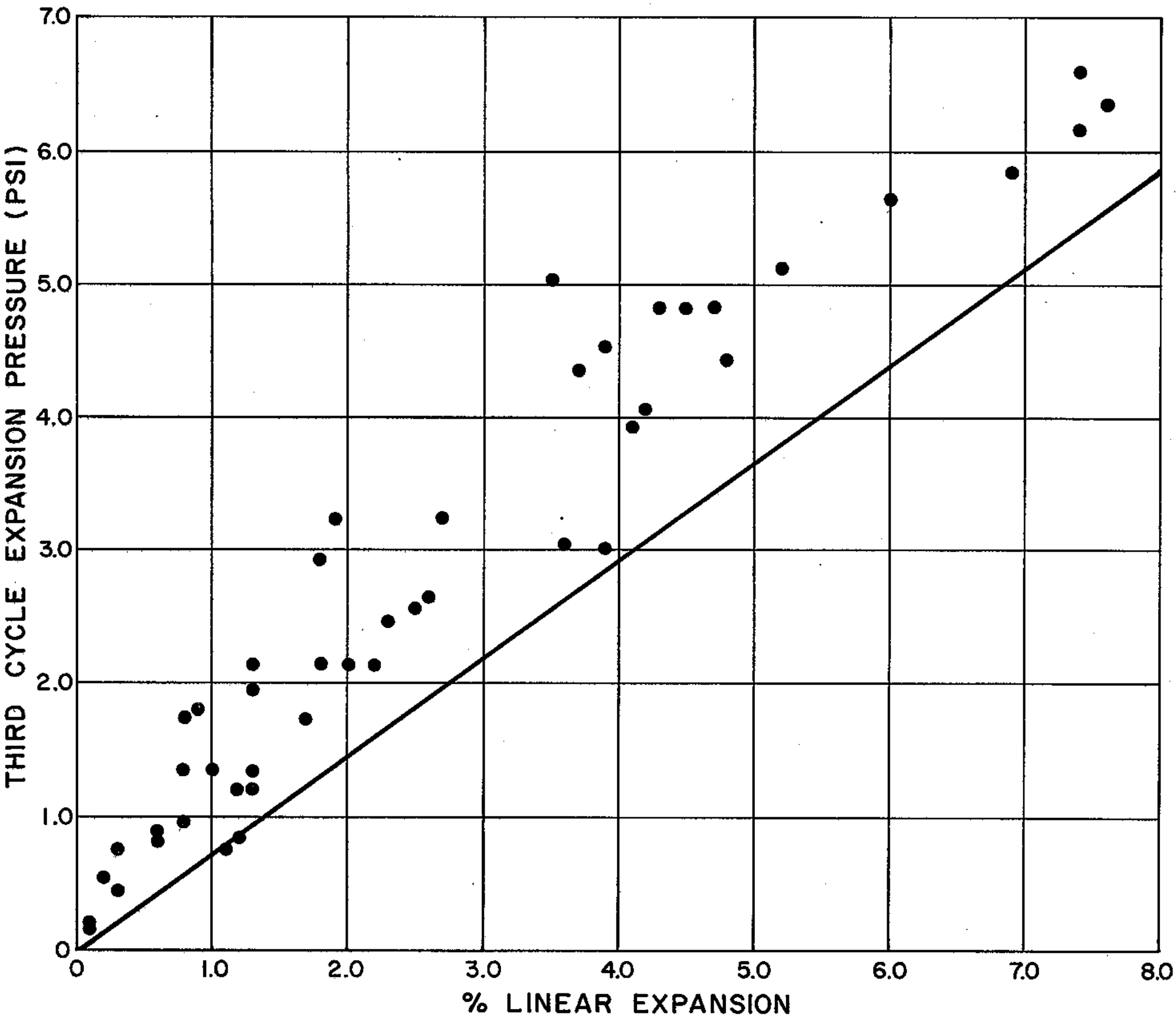
STRUCTURAL SECTION & OTHER DETAILS
04-Scl., Ala.-69-A,E
Gish Road to Warm Springs

Figure 7



MAXIMUM SAFE LINEAR EXPANSION FOR PCC PAVEMENTS
ALLOWABLE LINEAR EXPANSION CURVE
LINEAR EXPANSION VS COVER CURVE
DEPTH OF I.B. AS CONSTRUCTED, 20"
DEPTH BELOW PAVEMENT SURFACE (INCHES)
ALLOWABLE LINEAR EXPANSION (%)
5.7%
5.4%
5.1%
4.7%
4.3%
3.8%
3.2%
+1.7%
-1.7%
+1.4%
-1.4%
+1.1%
-1.1%
+0.7%
-0.7%
+0.3%
-0.3%
+0.2%
-0.2%
+0.8%
-0.8%
48"
42"
36"
30"
24"
18"
12"
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0

RELATIONSHIP OF THIRD CYCLE EXPANSION PRESSURE TO LINEAR EXPANSION 24" SURCHARGE



THE DETERMINATION OF ALLOWABLE THIRD CYCLE EXPANSION PRESSURE VALUES

Notes:

1. Surcharge lines determined from figs. 9, 10 and 6 (see text)
2. Allowable linear expansion values obtained from Table IV

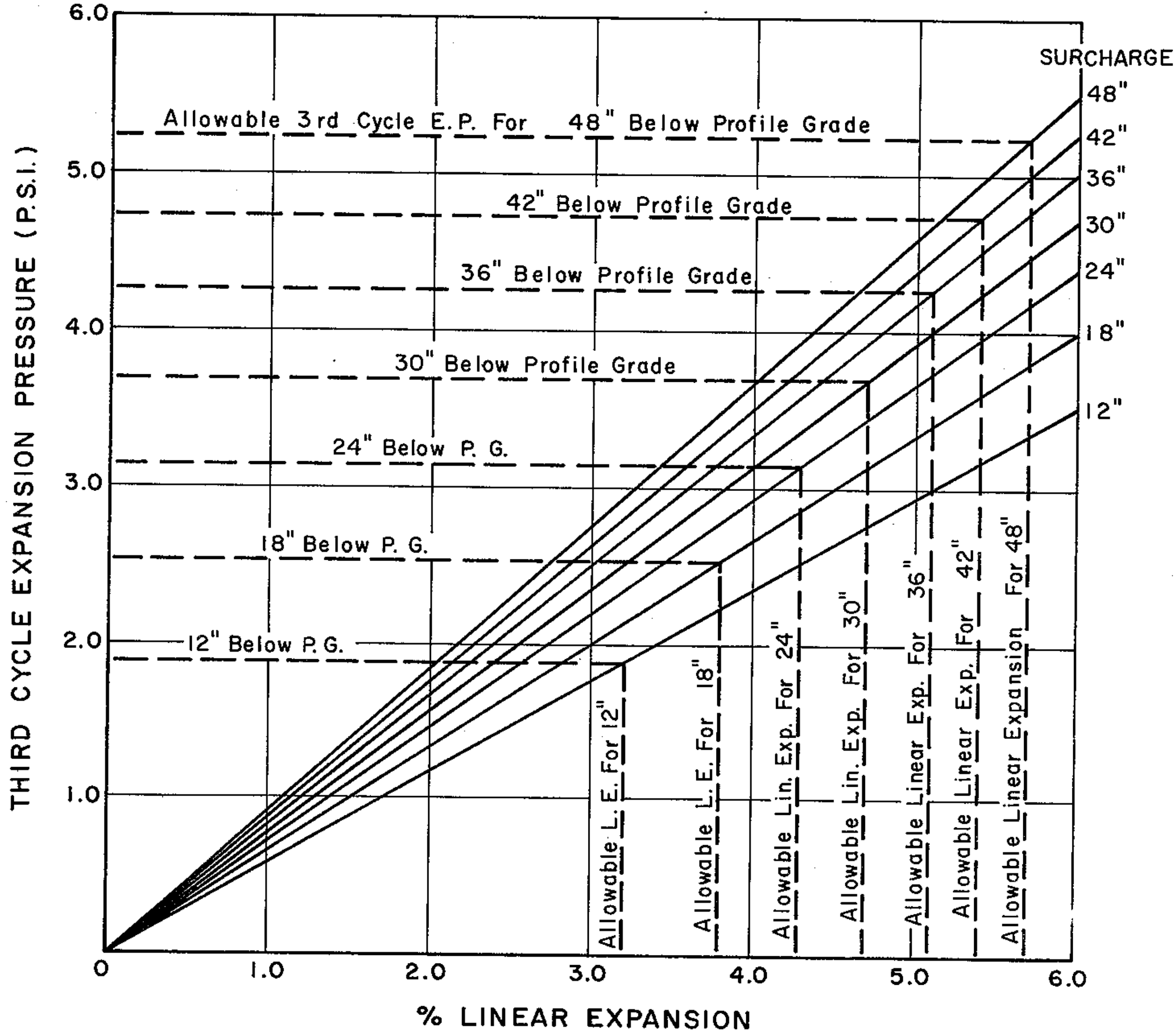


Figure 12

MATERIALS & RESEARCH DEPARTMENT

EXPANSION PRESSURE ANALYSIS OF SOILS UNDERLYING PCCP

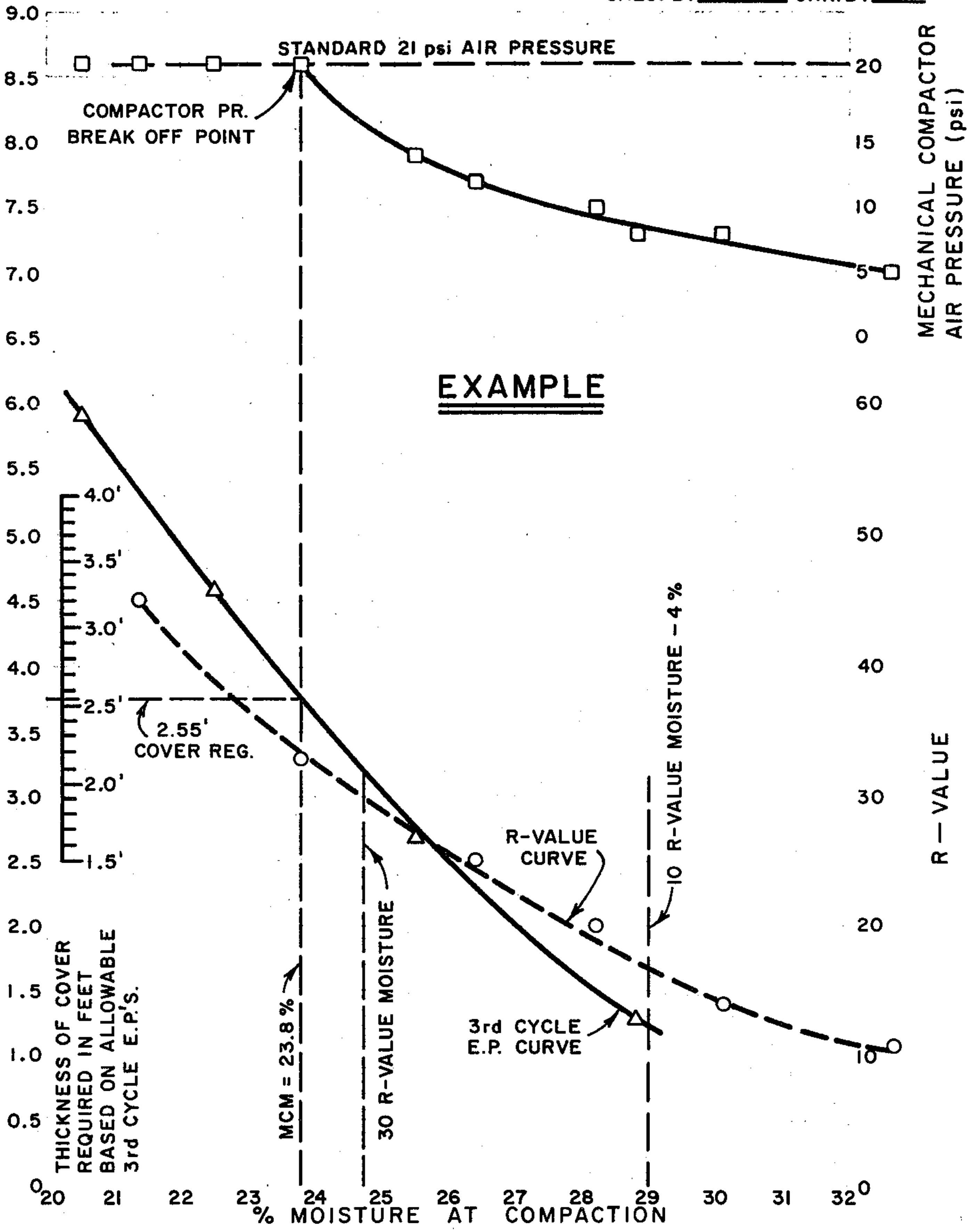
PROJECT ____________

W.O. NO. ____________

SAMPLE NO. 62-5910

DATE FEB. 21, 1963

CALC. BY WR CHK. BY MH



HMR T-3051 (REV. 7-64)

Figure 10

RELATIONSHIP OF THIRD CYCLE EXPANSION PRESSURE TO LINER EXPANSION 48" SURCHARGE

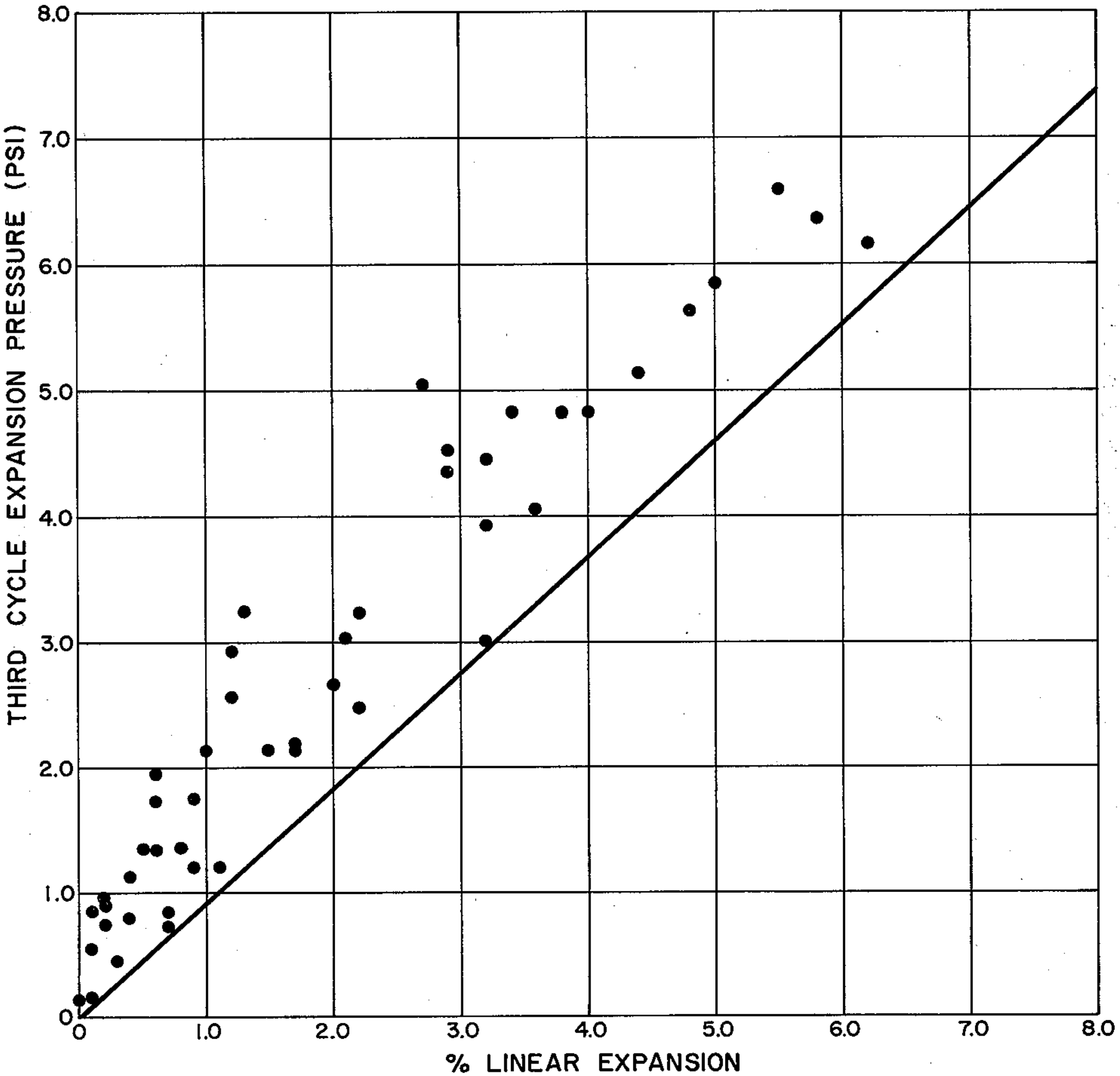


Figure 8

COMPARISON OF AVERAGE THIRD CYCLE EXPANSION PRESSURE - LINEAR EXPANSION VALUES FOR SAMPLES GROUPED ACCORDING TO SOIL CLASSIFICATION

NOTES:

(1) THIS CHART IS CONSTRUCTED IN THE SAME MANNER AS FIG. 3 EXCEPT THIRD DAY EXPANSION PRESSURES USED INSTEAD OF THE STANDARD 1 DAY EXPANSION PRESSURES.

(2) THE LINEAR EXPANSION TESTS WERE PERFORMED WITH 24" SURCHARGE.

LEGEND

Average points

△ Sandy silt & silts.

▲ Clayey silt

⊙ Silty clay

O Clay

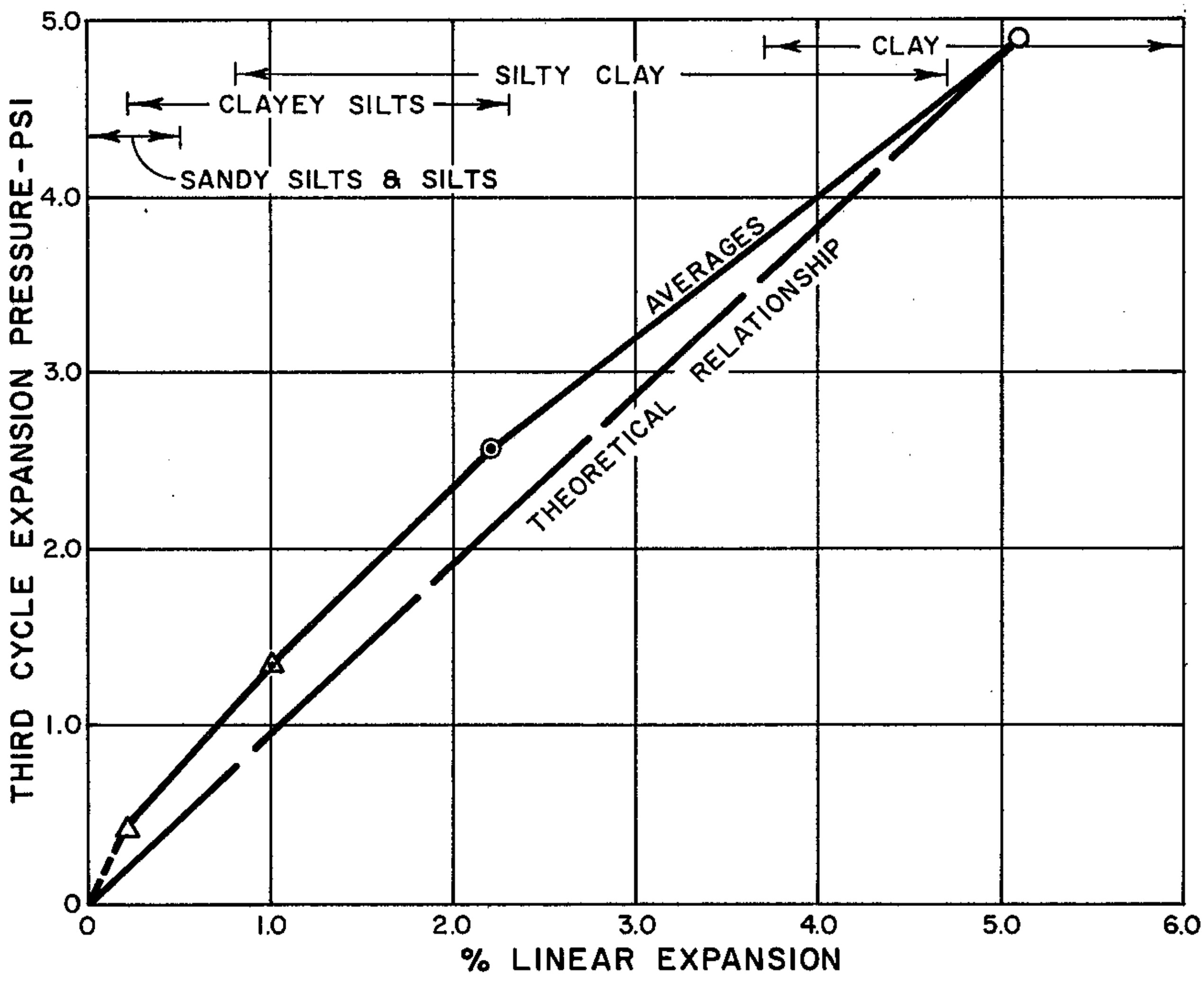


Figure 6

VARIATION IN LINEAR EXPANSION WITH DEPTH BELOW PCC PAVEMENT

BASED UPON TESTS PERFORMED ON EMBANKMENT MATERIAL FROM THE GISH ROAD TO WARM SPRINGS PROJECT

04-SCL, ALA-69-A,E

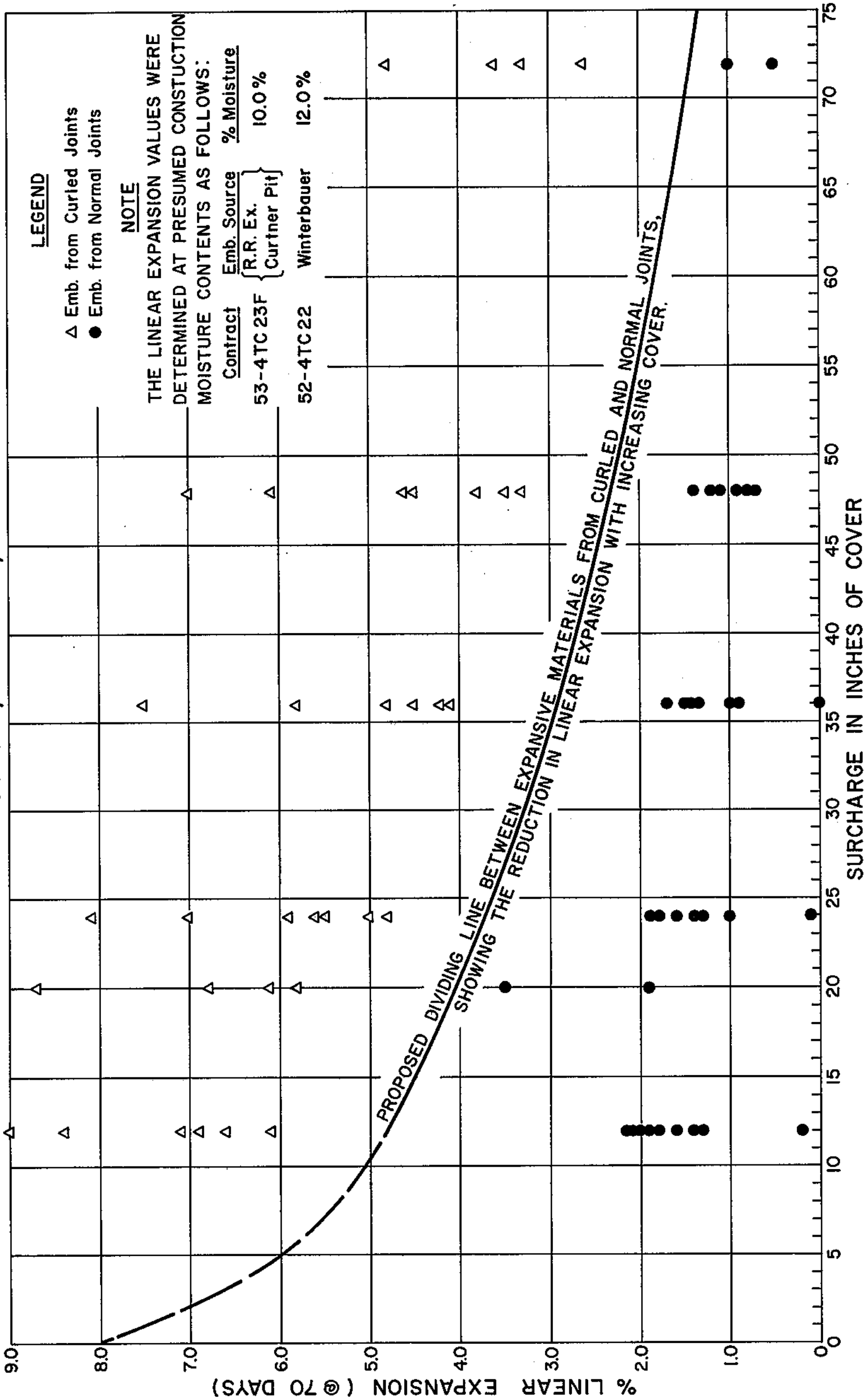
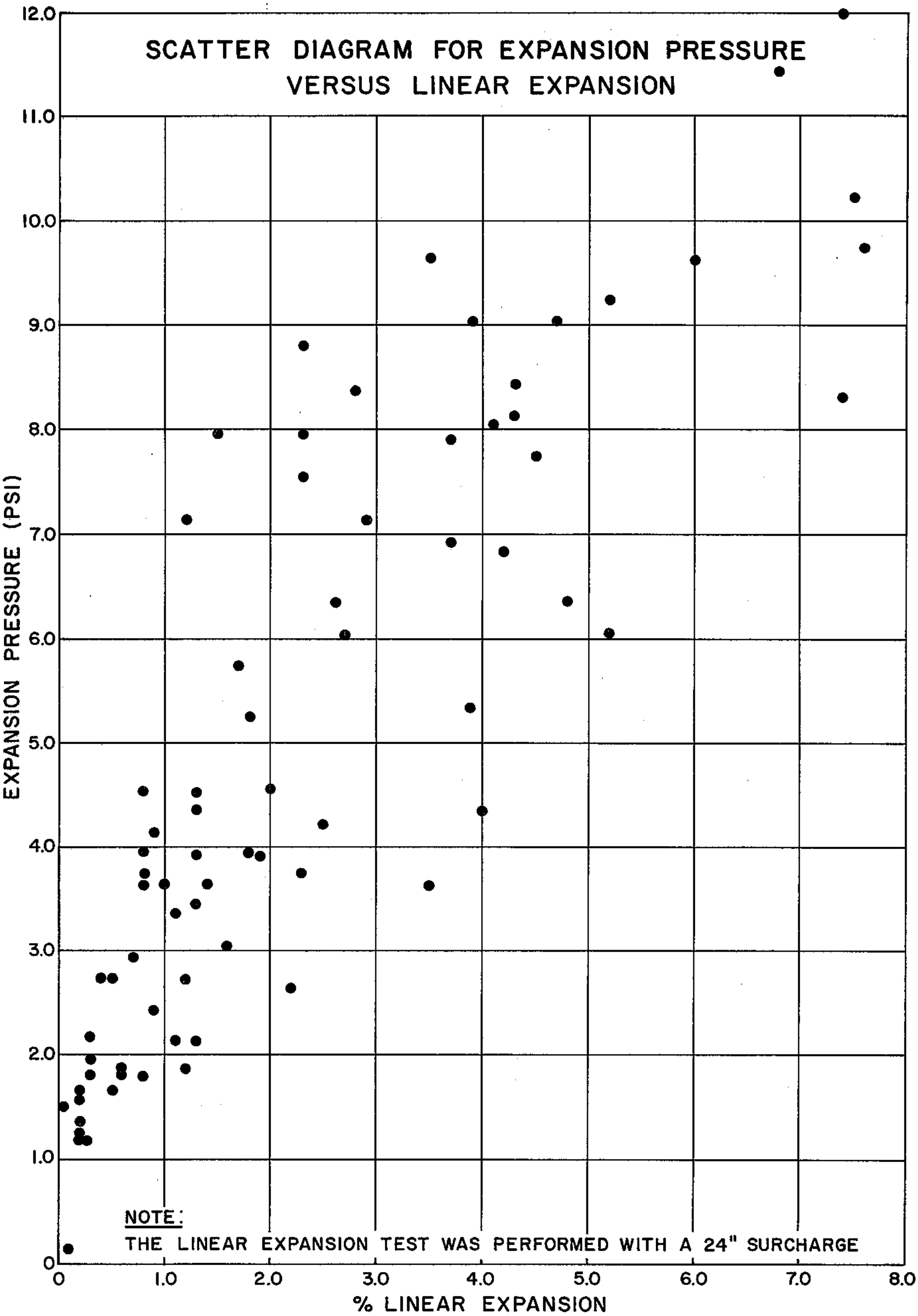


Figure 4



SCATTER DIAGRAM FOR EXPANSION PRESSURE VERSUS LINEAR EXPANSION
EXPANSION PRESSURE (PSI)
% LINEAR EXPANSION
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
NOTE:
THE LINEAR EXPANSION TEST WAS PERFORMED WITH A 24" SURCHARGE

Figure 2

PERCENTAGE OF EXPANSION FOR VARIOUS PLACEMENT CONDITIONS FOR SOIL UNDER A LOAD OF 1 PSI

(AFTER W. G. HOLTZ & H. J. GIBBS)

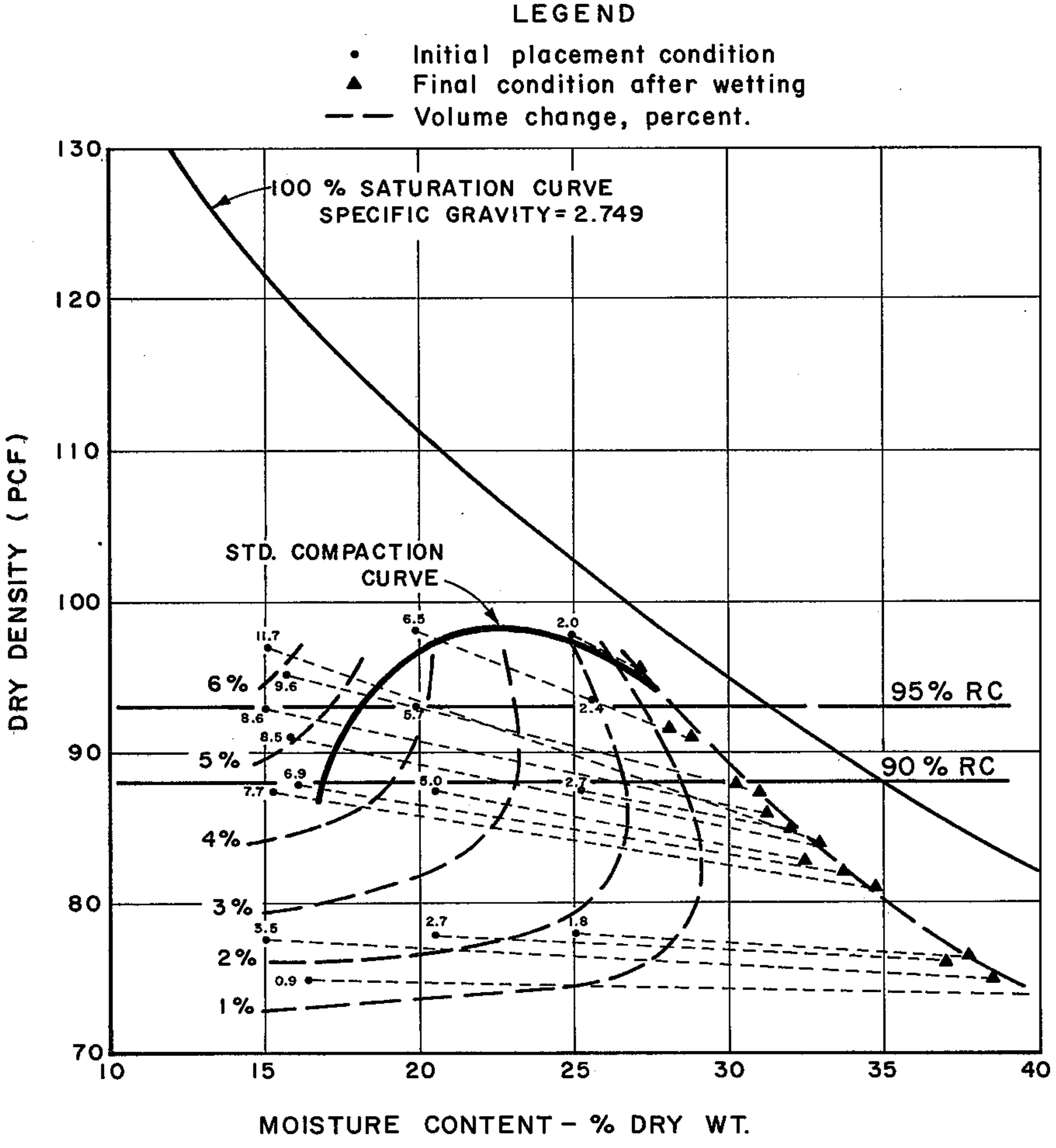
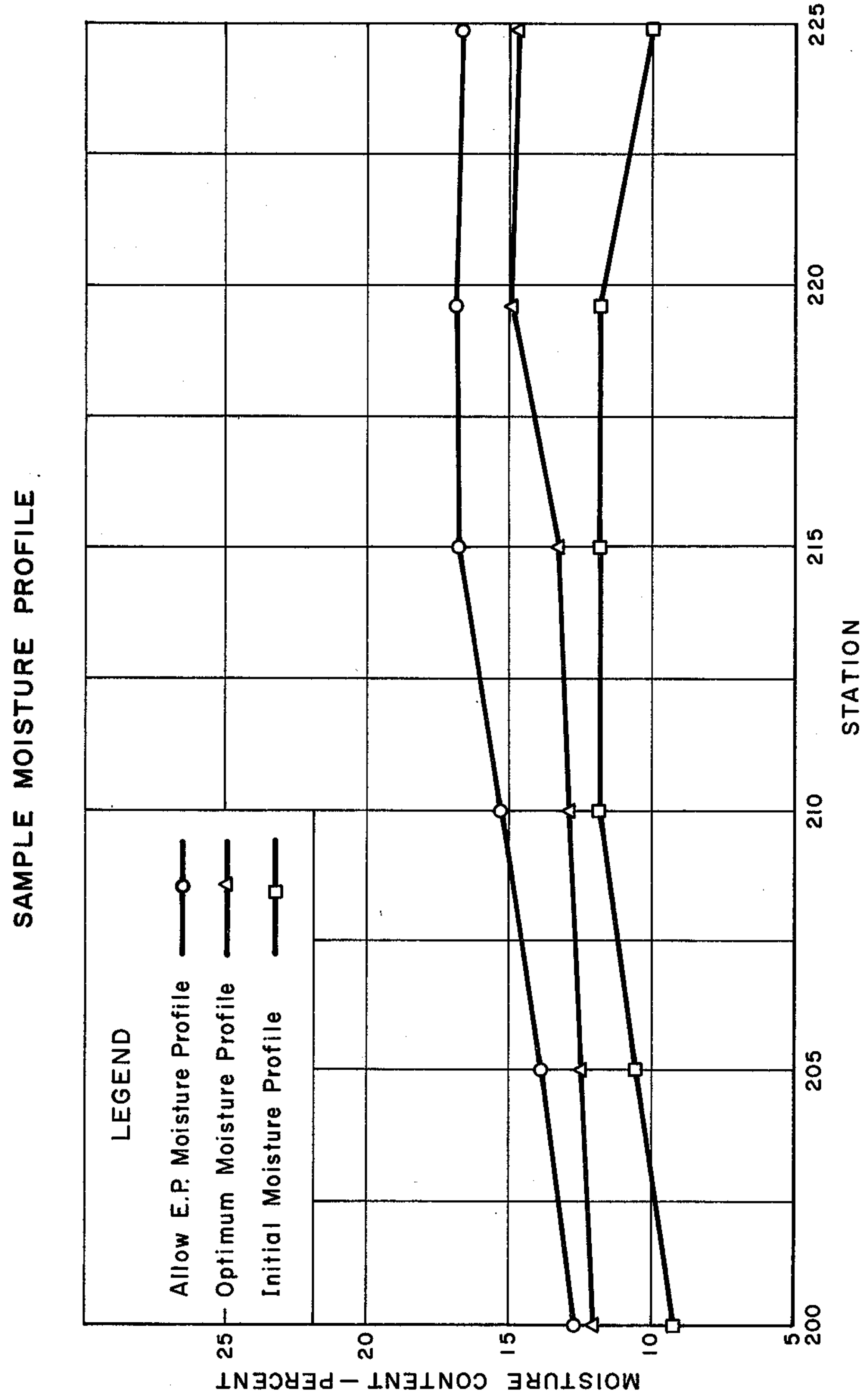


Figure 13



SAMPLE MOISTURE PROFILE
LEGEND
Allow E.P. Moisture Profile
Optimum Moisture Profile
Initial Moisture Profile
MOISTURE CONTENT — PERCENT
25
20
15
10
5
200
205
210
215
220
225
STATION

APPENDIX A

Description of the Linear Expansion Test:

The linear expansion test was devised as a means of evaluating the volumetric swell capacity of laboratory test specimens, fabricated under various conditions of moisture. It was through the use of this test that a series of allowable linear expansion values, corresponding to various thicknesses of cover, have been determined.

The test utilizes expansion pressure devices from the R-value test, which have been modified to admit free water to the bottom of the specimens as well as to the top. Pipe fittings are attached to the threaded turntable boss. Rubber gaskets and clamps are also provided, as shown in Figure A-I, to prevent water from leaking under the mold. In addition a circular screen (#16 mesh) is placed on the turntable to prevent material from clogging the water inlets and small corks are inserted in the vent holes in the rim of the turntable. When the test is performed, the assembly is connected by means of flexible rubber tubing to a water container which is placed to provide a head of about one foot on the specimen as illustrated in Figure A-II. About 200 mls of water is also placed in the mold on top of the specimen. These modifications aid in accelerating the process of expansion.

Essentially the test is quite simple. Standard sized R-value test specimens are fabricated in smooth steel molds with the mechanical compactor in the usual manner. This is followed by the application of a leveling load, in the testing press, of 350 psi. After a one-half hour standing period, for rebound, the specimens are placed in the EP device and the perforated discs with stems are set in position on the top of the specimens. With the deflection gage zeroed, the turntable is raised until the gage registers a deflection (in 1/10,000 of an inch) corresponding to the desired surcharge expressed in inches of cover (unit weight of cover assumed to be 130 lbs. per cu. ft.). Water is admitted to both ends of the specimen, as previously described, and the soil is allowed to expand. After the expansion pressure has increased for several hours, the pressure is released back to the surcharge value with turntable and the net gage reading (in 1/10,000 of an inch) is recorded. This process is repeated two or three times the first day and about two times each day for a week. Thereafter, it is usually only necessary to release once a day, weekends and holidays excepted. The net gage readings are thus accumulated for a period of 70 days. Experience has indicated that this amount of time is normally required to expend the major portion of the swell in most test specimens composed of expansive soils.

Percent linear expansion is calculated by dividing the total accumulated net gage readings at 70 days by the original specimen height (and multiplying by 100). While this value is based upon a one-dimensional measurement, it is actually an expression of percent volume change since the cross sectional area of the specimen is maintained constant, for all practical purposes, by the confinement of the heavy steel mold.

It can be seen that the unusually long time requirement (70 days) for this test precludes its use as a routine control method. Some limited use has been made of the test in Headquarters Laboratory as an aid to the districts in their preliminary design determinations. However, the linear expansion test has had its greatest value as a research tool in establishing the relationship between the laboratory volume change characteristics of soils and their field behavior.

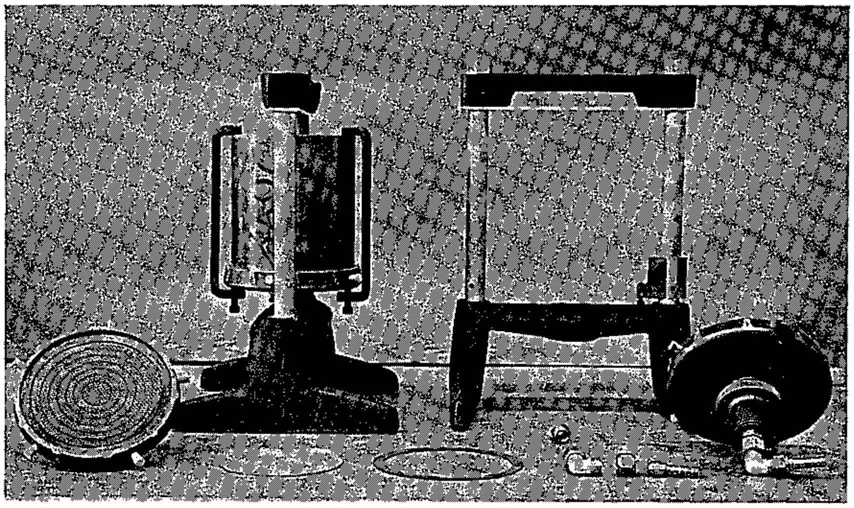


Figure A-I

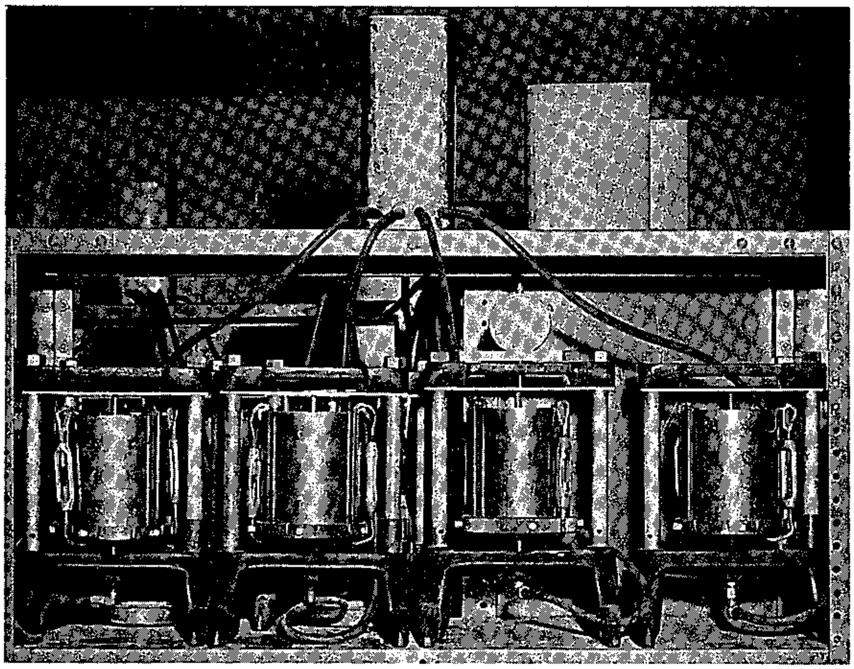


Figure A-II

State of California
Department of Public Works
Division of Highways

MATERIALS AND RESEARCH DEPARTMENT

Test Method No. Calif. 354-B
April 5, 1965
(10 pages)

METHOD OF TEST FOR EVALUATING THE EXPANSIVE POTENTIAL OF SOILS UNDERLYING PORTLAND CEMENT CONCRETE PAVEMENTS
(THIRD CYCLE EXPANSION PRESSURE TEST)

Scope

This method covers the procedure for performing the third cycle expansion pressure test upon soils which are intended to be incorporated in portland cement concrete (PCC) pavement structural sections. The method also includes the calculation of cover requirements along with the application of construction controls to safeguard PCC pavements against slab distortion (curling) caused by expansive subsoils.

This test method is divided into the following parts:

Part I. Modifications to Standard R-value Test as a Preliminary to Third Cycle Expansion Pressure Test

Part II. Method of Test for Determining Third Cycle Expansion Pressures

Part III. Method of Analysis for Design and Application to Construction Control

PART I. MODIFICATIONS TO STANDARD R-VALUE TEST AS A PRELIMINARY TO THIRD CYCLE EXPANSION PRESSURE TEST

The first test, which must be undertaken on soil samples submitted for expansive potential analysis, is the standard R-value test, Test Method No. Calif. 301.

The R-value test is performed in the normal manner except that additional specimens are prepared at moisture contents which will span the R-value range of 10 to 30 and will also show where the mechanical compactor foot pressure has to be reduced below 21 pounds. Some experience on the part of the operator is required to determine the range of moisture at the time of fabricating specimens. The following guides will assist the operator:

1. Fabricate at least two specimens at moisture contents low enough to provide firm specimens which will permit the use of full mechanical compactor foot pressure (350 psi) during the application of the 100 tamps as described in Part II, Section E-6 of Test Method No. Calif. 301. The moisture contents at compaction, of these specimens, should be arranged to span over a range of at least 3% moisture.

It is also desirable that the moisture content of the wettest specimen in this group should be as near as possible to the point where the compactor foot pressure must be reduced because of excessive penetration of the foot (see Part II Section E-7 of Test Method No. Calif. 301). Since the compactor air pressure, used to control the California type mechanical compactor, is directly proportional to the applied foot pressure, it is convenient to use air pressure values as expressions of foot pressure. Normally the compactor is calibrated on a load cell to provide the full 350 psi foot pressure at about 21 psi air pressure. Therefore, record 21 psi air pressure on the work card, Form T-361, where the full 350 psi foot pressure is used. Record necessary reductions in air pressure as proportionally decreased foot pressures are used.

2. Fabricate additional test specimens at moisture contents high enough to reduce expansion pressures to a negligible amount and also cover the range of moistures suitable for determining an R-value at equilibrium for the soil sample. Among this group of specimens there must be at least three specimens which, due to softness at the elevated moistures, require the reduction of foot pressure (recorded as compactor air pressure) to prevent the penetration of the compactor foot in excess of ¼ inch in accordance with Part II, Section E-7 of Test Method No. Calif. 301.

3. Exudation pressures are determined in the normal manner when specimens range between 100 (or less) and 800 psi exudation pressure. However, the specimens drier than the 800 psi exudation pressure level should be given only an 800 psi static load for leveling purposes. After compaction, subject all of the specimens to the normal expansion pressure and stabilometer phases of the R-value test (Calif. 301).

The standard R-value test series serves two purposes. First, it provides the equilibrium R-value of the material for stability determinations of the soil for the primary structural section design. Secondly, the individual R-value test specimens and the compactor air pressures are needed in the third cycle expansion pressure analysis for PCC curl potential. (See Part III). The requirements stipulated in items 1 and 2 above, regarding the compactor air pressures, are also essential for establishing the proper moisture range for fabricating both R-value and subsequent third cycle expansion pressure test specimens.

Record the R-value test data on the work card Form T-361 as shown in the example Figure I.

PART II. METHOD OF TEST FOR DETERMINING THIRD CYCLE EXPANSION PRESSURES

Procedure

A. Apparatus

The equipment and tools required for this procedure are the same as those described in Parts I to V, inclusive, of Test Method No. Calif. 301.

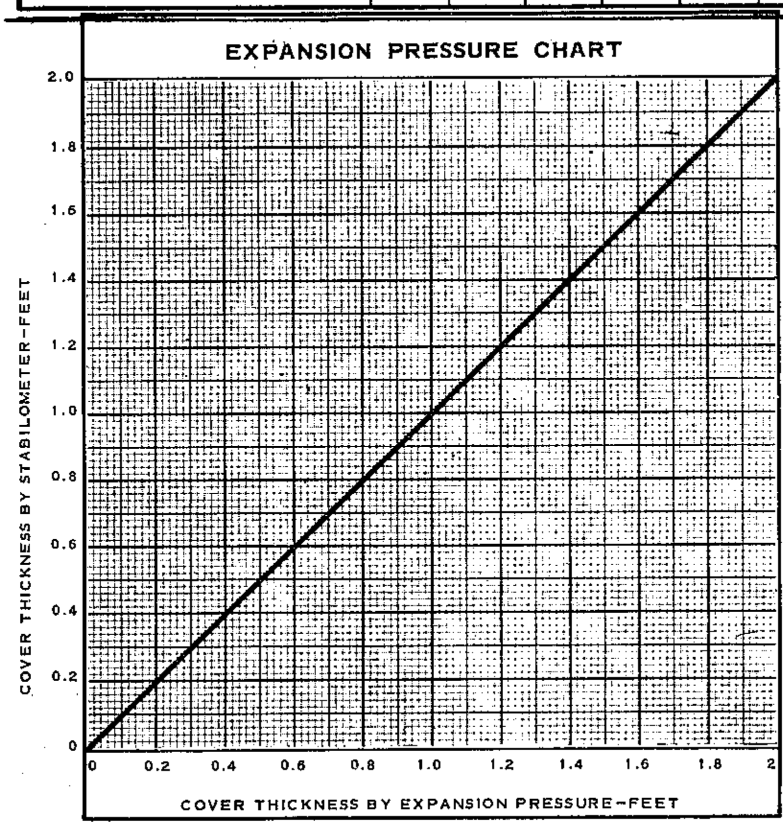
B. Test Record Form

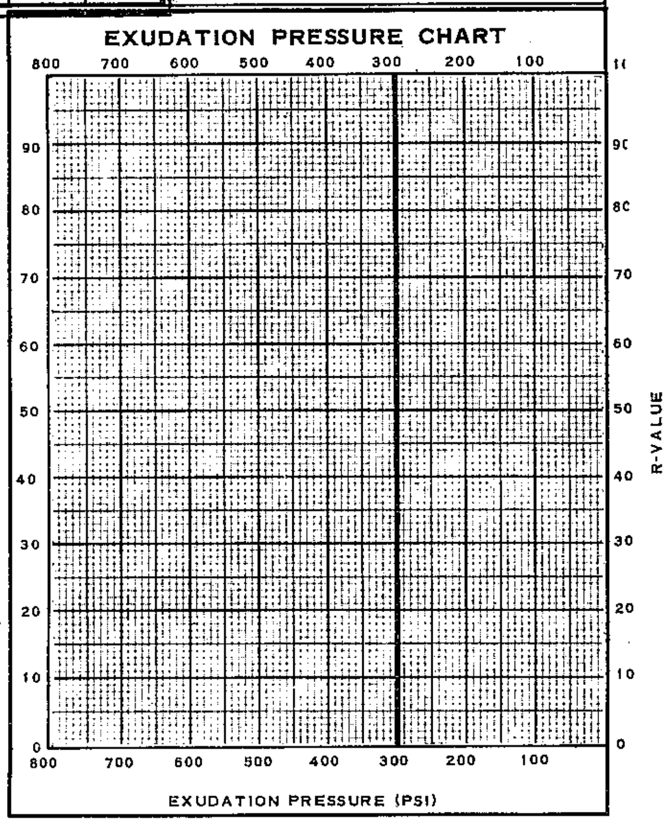
Keep all pertinent data regarding the test specimens on individual test tickets (Form T-328W). Assign a ticket at the time of preparation of the material for the specimen, and keep it with the specimen until the third cycle expansion pressure test is completed. At the start of the third cycle expansion pressure test, copy all data onto the work card, Form T-361, as shown in the example illustrated in Figure II.

TEST NO. 62-5910 DIST. CO. RTE. SEC. CONT. NO.

TEST SPECIMEN	A	B	C	D	E	F	G	H
DATE TESTED								
COMPACTOR AIR PRESS-PSI	21	21	14	8				
INITIAL MOISTURE-%	6.8	6.8	6.8	6.8				
SOAK WATER-ML	70	70	70	70				
WATER ADDED-ML (TOTAL)	141	162	193	227				
WATER ADDED-%	13.7	15.7	18.7	22.0				
MOISTURE AT COMPACTION-%	20.5	22.5	25.5	28.8				
WET WEIGHT OF BRIQUETTE-GMS.	1016	1046	1021	1035				
HEIGHT OF BRIQUETTE-INCHES	2.51	2.53	2.49	2.51				
DENSITY-LB. PER CU. FT.	102	102	99	97				
STABILOMETER PH AT 1000 LBS.								
2000 LBS.								
DISPLACEMENT								
R-VALUE								
EXUDATION PRESSURE-P.S.I.	(350 STATIC)							
STAB. THICK-FEET								
3rd Cycle Gauge Reading ~~EXPANSION PRESSURE~~	196	153	90	43				
EXPAN PRESS 3rd CY ~~THICK-FEET~~ psi	5.9	4.6	2.7	1.3				
1st Cycle Gauge Reading	387	264	148	96				
2nd Cycle Gauge Reading	250	189	113	62				

	SP. GR.	FINE	COARSE
	AS REC'D		
	CRUSHED		
L.L.	P.L.	P.I.	SPEC.
	% CRUSHED		SPEC.
	P.I. x % 200		SPEC.
S.E.	AS REC'D		SPEC.
S.E.	CRUSHED		SPEC.
S.E.	COMBINED		SPEC.
LART	100 REV.		SPEC.
LART	500 REV.		SPEC.
DUR.	FINE		SPEC.
DUR.	COARSE		SPEC.
SUBBASE			
BASE			
SURFACE			
GRAVEL EQUIVALENT FACTOR			
TRAFFIC INDEX			
R-VALUE	BY EXUD PRESS		
R-VALUE	BY EXPAN PRESS		
R-VALUE	AT EQUIL		SPEC.
COVER FOR ABOVE COND. (FEET)			





FORM T-361 (REV. 5-64)

Figure II

Test Method No. Calif. 354-B
April 5, 1965

CHART TO DETERMINE EXPANSION PRESSURE IN PSI FROM E.P. DIAL READINGS

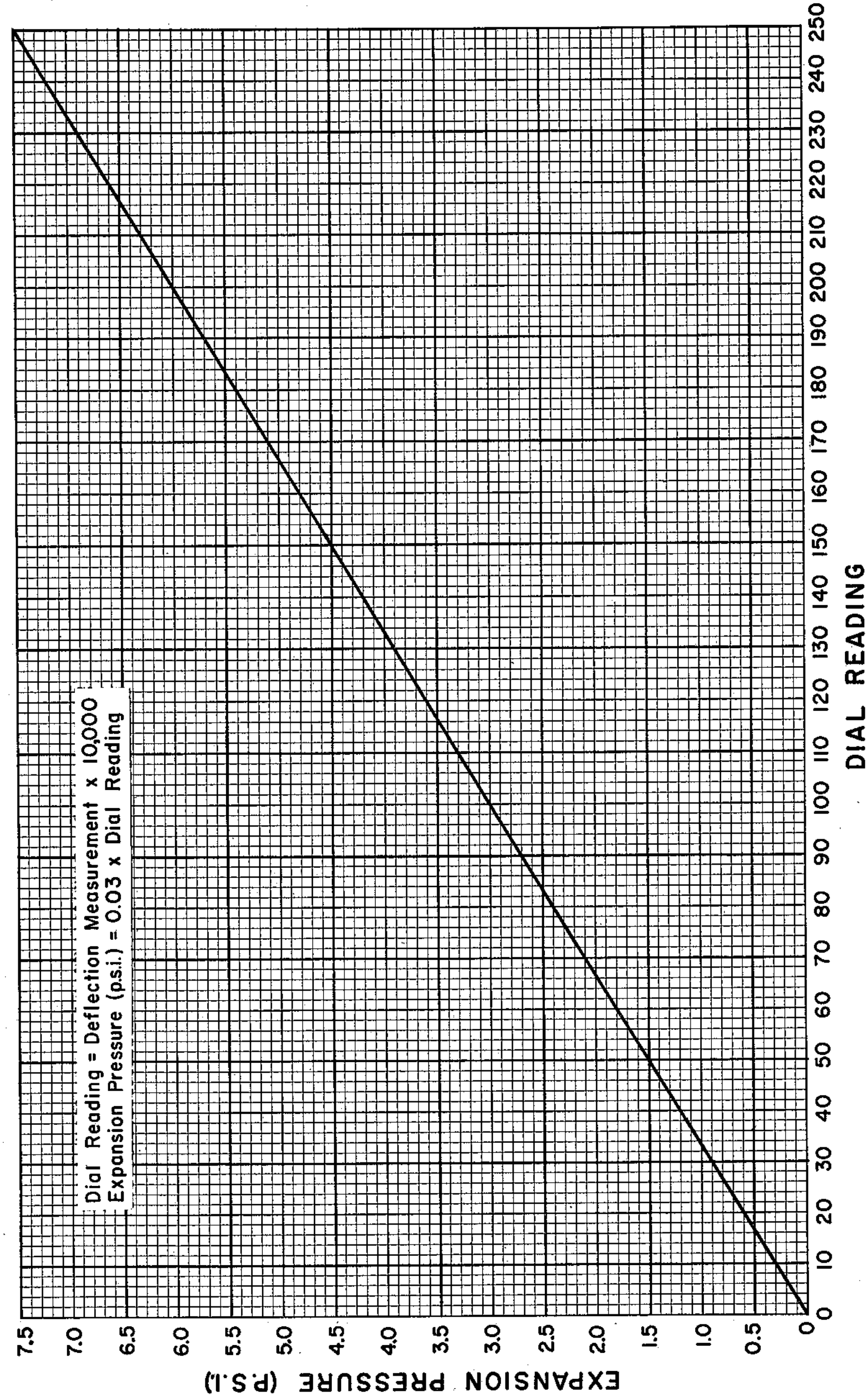


Figure III

A. Test Record Form

Use the chart, Form T-3051, for analyzing data.

B. Design Analysis

1. Plot R-value, compactor air pressure and third cycle expansion pressure test data, as determined in Part I and Part II, against moisture content at compaction on Form T-3051 as illustrated in Figure IV.

2. Connect the plotted points with respective smooth curves. In the case of the compactor air pressures, interpret a smooth curve (normally concave upward) from the "reduced" air pressure points (less than 21 psi) and extrapolate to intersect the 21 psi line. This intersection will not necessarily coincide with the "wettest" 21 psi point but will, more often than not, intersect somewhat to the right of this point (see example in Figure IV).

3. Since it is desired to obtain the most economical structural section which will safeguard against PCC curl, the final thickness of cover, over the expansive soil, will be primarily dependent upon the highest moisture level which can be attained in construction and still maintain workability or firmness of the working table to permit construction operations. Therefore, the next step, in this analysis, is to establish a minimum control moisture (MCM) content which will allow a reasonable range of workability up to a limiting moisture level. This is accomplished by determining from the previously plotted curves (on Form T-3051) which of the following three criteria provide the lowest moisture content:

   a. Moisture content at the intersection of the reduced compactor air pressure curve with 21 psi air pressure (commonly referred to as "compactor pressure break-off point").
   b. Moisture content at 30 R-value (as interpreted from the R-value curve).
   c. Moisture content at 10 R-value minus 4% moisture.

4. After determining the MCM as the least of the above three moisture contents, refer to the inside scale on the left ordinate of Form T-3051 or the following Table I for allowable third cycle expansion pressure values corresponding to various depths below profile grade:

TABLE I
MAXIMUM ALLOWABLE THIRD CYCLE EXPANSION PRESSURES

Depth Below Profile Grade (feet)	*Third Cycle E. P. lb. per sq. inch*
1.5′	2.5
2.0′	3.1
2.5′	3.7
3.0′	4.3
3.5′	4.8
4.0′	5.3

5. Enter the abscissa of the chart at the MCM and note the intersection with the third cycle E.P. curve. Read the thickness of cover required, at this intersection, from the ordinate scale (to the nearest 0.1 foot). This is the design thickness of the structural section over the soil represented by the sample while the MCM represents the *minimum* moisture content which must be attained in the top one foot of the basement soil, during construction, for the particular thickness of structural section determined. In addition, the MCM must be maintained during construction until upper layers are placed to prevent the escape of moisture from the basement soil.

Notes

The above analysis processes are probably most effectively demonstrated by the use of examples. Therefore the following three examples are given in order to cover analysis situations which are most frequently encountered in practice. The first example is quite straightforward and demonstrates the basic principles of analysis. Examples 2 and 3 concern special situations when soils of low expansive potential are involved.

Example No. 1 (Figure IV)

The test data for the sample illustrated in this example is shown on the work cards in Figures I and II. Referring to Figure IV, this data is plotted on Form T-3051 and appropriate smooth curves are drawn through the respective points. The moisture contents related to the three criteria (see Section B-3 Items (a), (b), and (c) of this Part III) are then interpolated from the curves, as shown. These moisture contents are listed, for this example, as follows:

Moisture at compactor air pressure break-off point	=24.2%
Moisture at 30 R-value	=24.6%
Moisture at 10 R-value—4%	=29.0%

Since the compactor air pressure break-off point gives the lowest moisture value, 24.2%, this becomes the "minimum control moisture" (MCM). Intersection of the MCM with the third cycle E.P. curve indicates that 2.3 feet of cover will be required over soil represented by this sample.

Example No. 2 (Figure V)

This example illustrates a method for determining whether the expansive potential of a soil is sufficient to warrant any consideration from design and moisture control standpoints. It is noted that, in this case, the 10 R-value moisture minus 4% is the governing criteria and would be the MCM. However, it is also noted that the third cycle E.P. at this point is only 0.2 psi and at more than 2½% moisture below the MCM the pressure only raises to 0.9 psi. As a rule, when third cycle E.P. specimens, fabricated at least 2% moisture below the MCM, do not indicate third cycle EP's in excess of 1 psi, then the soil sample is considered *non-expansive* for the purpose of this test method.

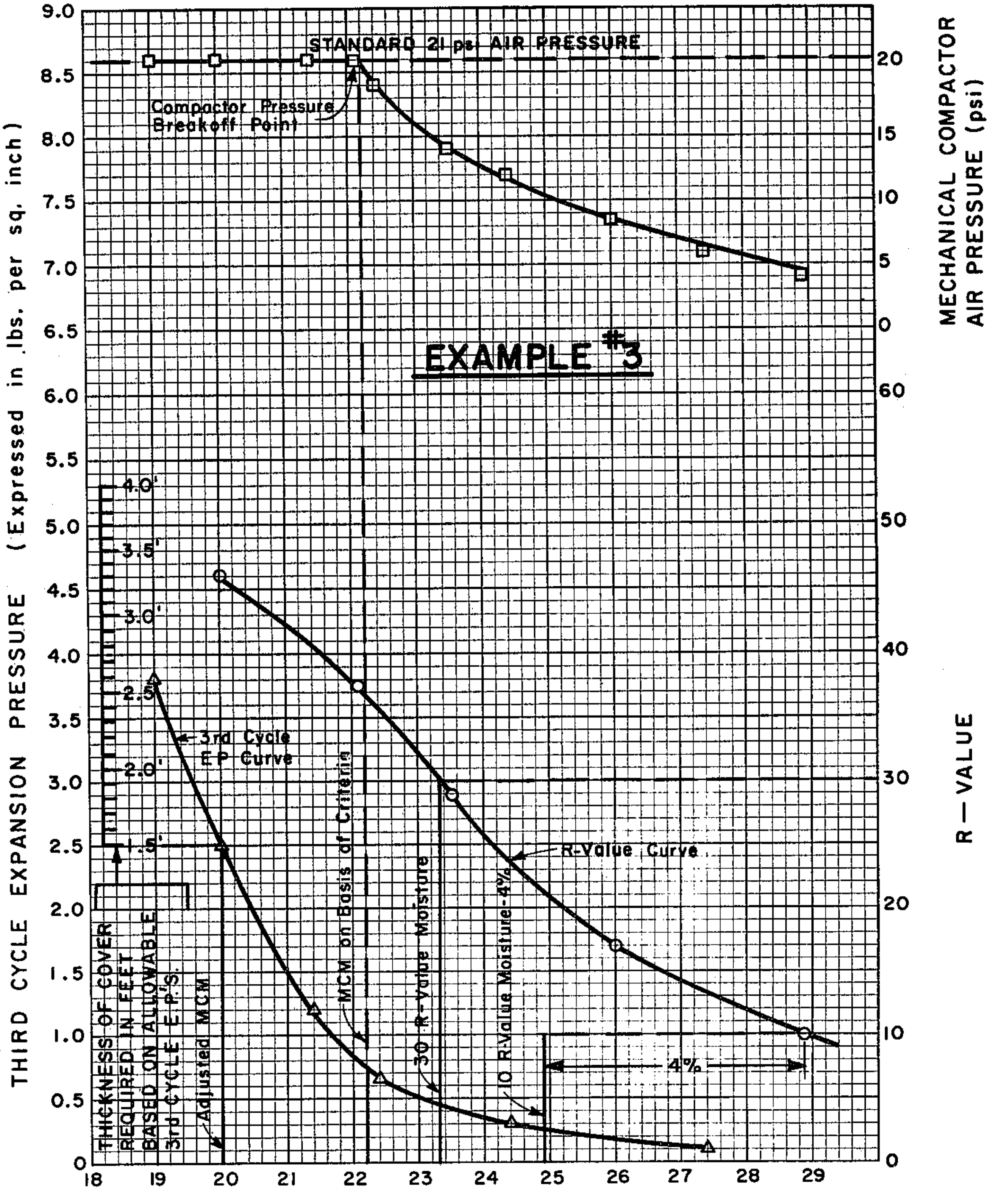
Example No. 3 (Figure VI)

The soil represented by this sample is also relatively low in expansive potential. It is noted that at

MATERIALS & RESEARCH DEPARTMENT

EXPANSION PRESSURE ANALYSIS OF SOILS UNDERLYING PCCP

PROJECT ____
W.O. NO. ____
SAMPLE NO. ____
DATE ____
CALC. BY ____ CHK. BY ____



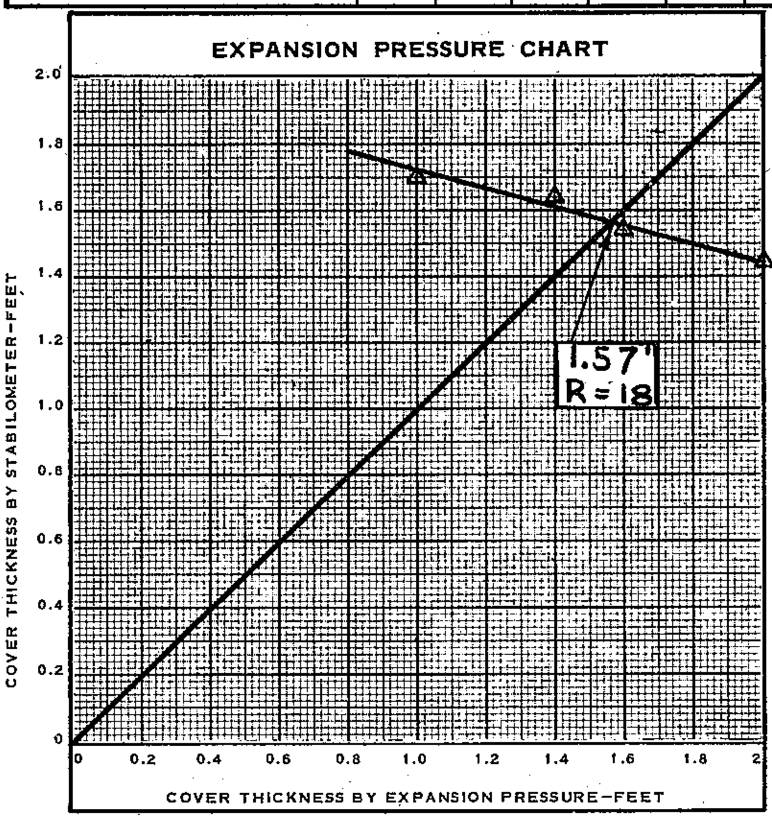
FORM T-3051 (REV. 7-64)

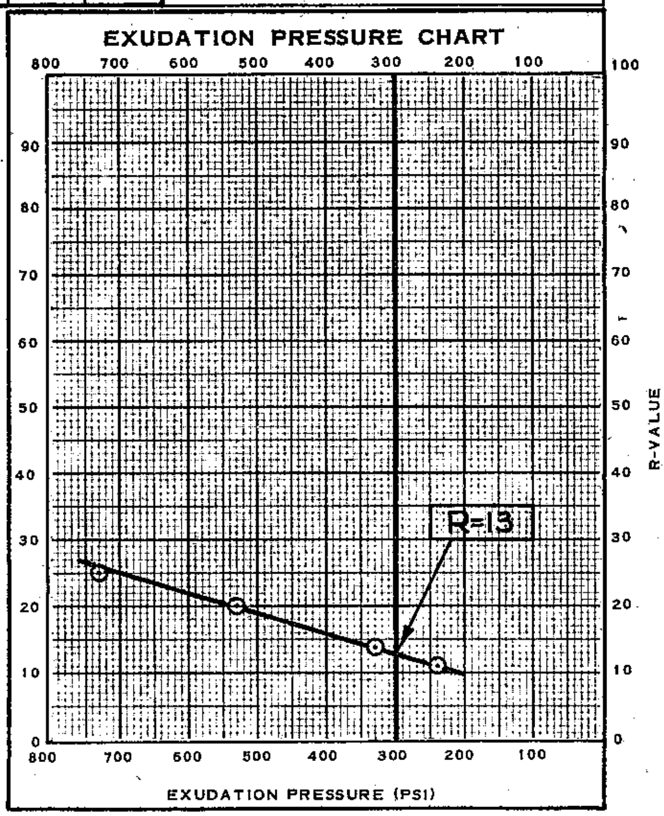
Figure VI

TEST NO. 62-5910 DIST. ____ CO. ____ RTE. ____ SEC. ____ CONT. NO. ____

TEST SPECIMEN	A	B	C	D	E	F	G	H
DATE TESTED								
COMPACTOR AIR PRESS~PSI	21	21	12	10	8	5		
INITIAL MOISTURE~%	6.8	6.8	6.8	6.8	6.8	6.8		
SOAK WATER~ML	70	70	70	70	70	70		
WATER ADDED~ML (TOTAL)	150	175	200	220	240	265		
WATER ADDED~%	14.6	17.0	19.4	21.4	23.3	25.7		
MOISTURE AT COMPACTION~%	21.4	23.8	26.4	28.2	30.1	32.5		
WET WEIGHT OF BRIQUETTE~GMS.	1022	1034	1033	1017	990	1010		
HEIGHT OF BRIQUETTE~INCHES	2.49	2.51	2.50	2.49	2.46	2.54		
DENSITY~LB. PER CU. FT.	103	101	99	97	94	91		
STABILOMETER PH AT 1000 LBS.	30	33	41	48	54	60		
2000 LBS.	78	96	111	121	129	135		
DISPLACEMENT	3.20	3.30	3.35	3.20	3.70	3.70		
R-VALUE	45	33	25	20	14	11		
EXUDATION PRESSURE~P.S.I.	800	800	730	530	330	240		
STAB. THICK~FEET			1.44	1.54	1.64	1.70		
EXPANSION PRESSURE			60	48	42	30		
EXPAN PRESS THICK~FEET			2.00	1.60	1.40	1.00		

SP. GR.		FINE	COARSE
AS REC'D			
CRUSHED			
L.L. 53	P.L. 32	P.I. 21	SPEC.
% CRUSHED			SPEC.
P.I. x % 200			SPEC.
S.E.	AS REC'D	1	SPEC.
S.E.	CRUSHED		SPEC.
S.E.	COMBINED		SPEC.
LART	100 REV.		SPEC.
LART	500 REV.		SPEC.
DUR.	FINE		SPEC.
DUR.	COARSE		SPEC.
SUBBASE			
BASE			
SURFACE			
GRAVEL EQUIVALENT FACTOR		1.0 Assumed	
TRAFFIC INDEX		6.0 Assumed	
R-VALUE	BY EXUD PRESS	13	
R-VALUE	BY EXPAN PRESS	18	
R-VALUE	AT EQUIL	13	SPEC.
~~COVER FOR ABOVE COND. (FEET)~~			





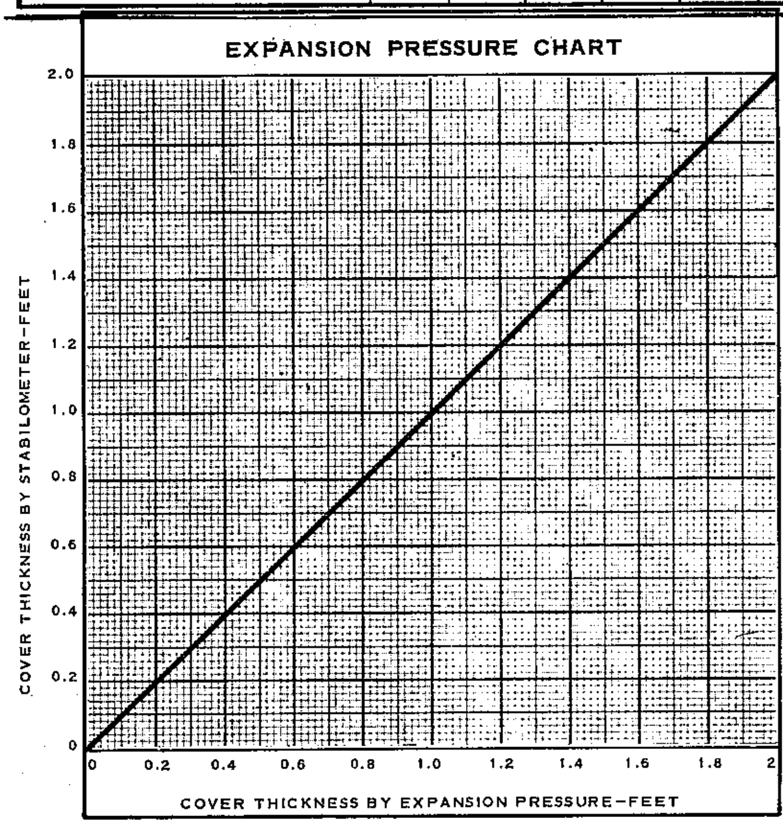
FORM T-361 (REV. 5-64)

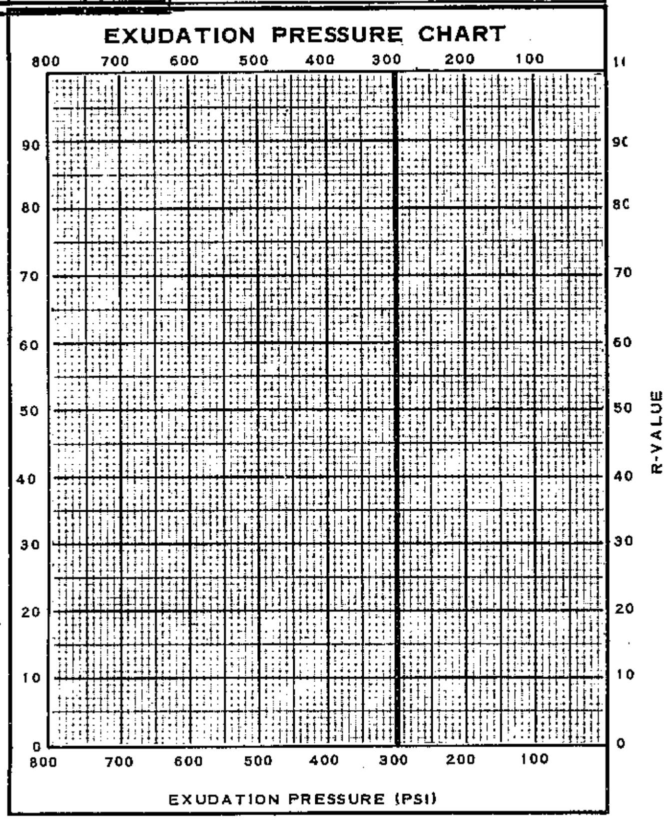
Figure I

TEST NO. 62-5910 DIST. CO. RTE. SEC. CONT. NO.

TEST SPECIMEN	A	B	C	D	E	F	G	H
DATE TESTED								
COMPACTOR AIR PRESS-PSI	21	21	14	8				
INITIAL MOISTURE-%	6.8	6.8	6.8	6.8				
SOAK WATER-ML	70	70	70	70				
WATER ADDED-ML (TOTAL)	141	162	193	227				
WATER ADDED-%	13.7	15.7	18.7	22.0				
MOISTURE AT COMPACTION-%	20.5	22.5	25.5	28.8				
WET WEIGHT OF BRIQUETTE-GMS.	1016	1046	1021	1035				
HEIGHT OF BRIQUETTE-INCHES	2.51	2.53	2.49	2.51				
DENSITY-LB. PER CU. FT.	102	102	99	97				
STABILOMETER PH AT 1000 LBS.								
2000 LBS.								
DISPLACEMENT								
R-VALUE								
EXUDATION PRESSURE-P.S.I.	(350 STATIC)							
STAB. THICK-FEET								
3rd Cycle Gauge Reading ~~EXPANSION PRESSURE~~	196	153	90	43				
EXPAN PRESS 3rd CY ~~THICK-FEET~~ psi	5.9	4.6	2.7	1.3				
1st Cycle Gauge Reading	387	264	148	96				
2nd Cycle Gauge Reading	250	189	113	62				

SP. GR.		FINE	COARSE
AS REC'D			
CRUSHED			
L.L.	P.L.	P.I.	SPEC.
% CRUSHED			SPEC.
P.I. x % 200			SPEC.
S.E.	AS REC'D		SPEC.
S.E.	CRUSHED		SPEC.
S.E.	COMBINED		SPEC.
LART	100 REV.		SPEC.
LART	500 REV.		SPEC.
DUR.	FINE		SPEC.
DUR.	COARSE		SPEC.
SUBBASE			
BASE			
SURFACE			
GRAVEL EQUIVALENT FACTOR			
TRAFFIC INDEX			
R-VALUE	BY EXUD PRESS		
R-VALUE	BY EXPAN PRESS		
R-VALUE	AT EQUIL		SPEC.
COVER FOR ABOVE COND. (FEET)			





FORM T-361 (REV. 5-64)

Figure II

CHART TO DETERMINE EXPANSION PRESSURE IN PSI FROM E.P. DIAL READINGS

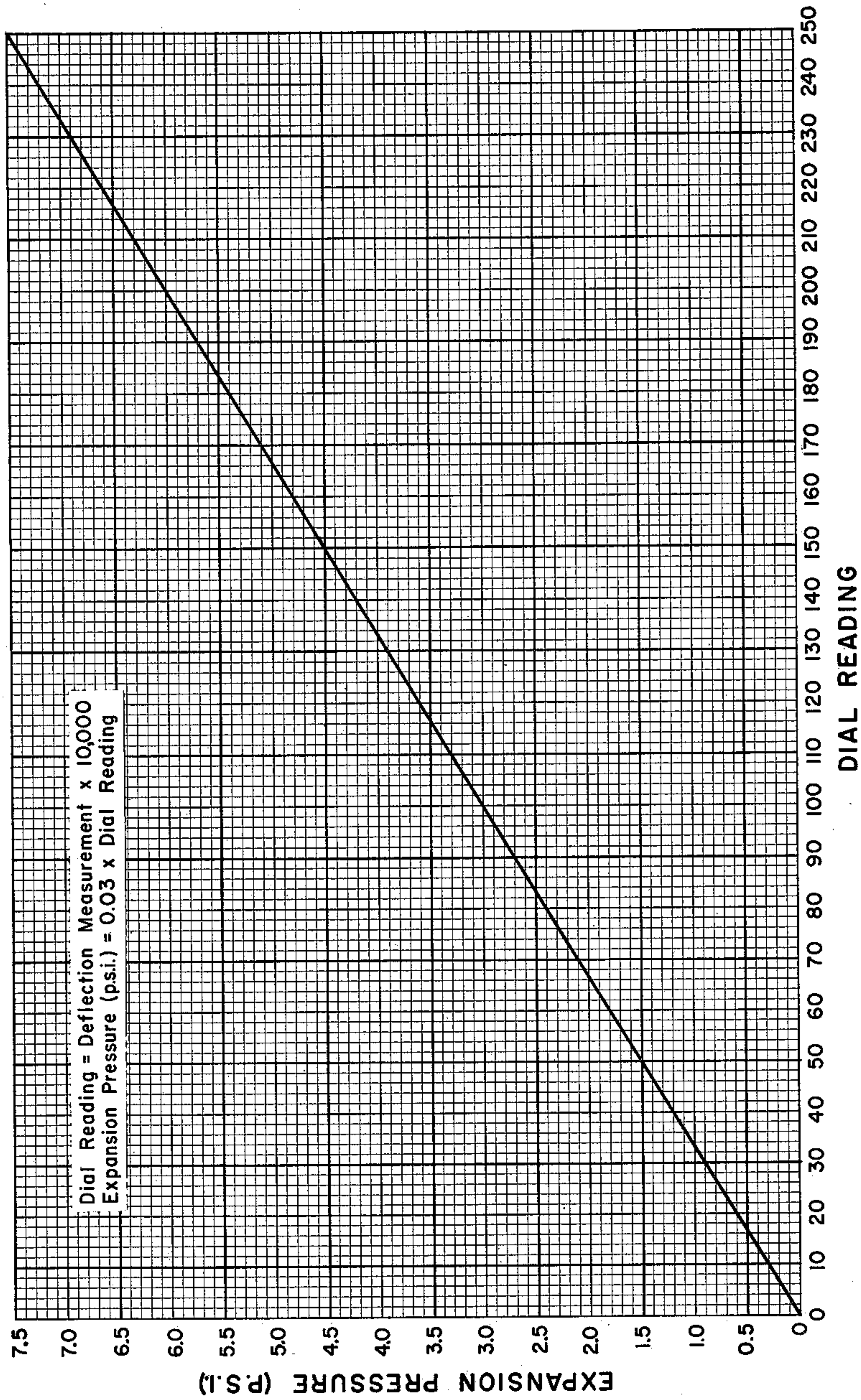


Figure III

A. Test Record Form

Use the chart, Form T-3051, for analyzing data.

B. Design Analysis

1. Plot R-value, compactor air pressure and third cycle expansion pressure test data, as determined in Part I and Part II, against moisture content at compaction on Form T-3051 as illustrated in Figure IV.

2. Connect the plotted points with respective smooth curves. In the case of the compactor air pressures, interpret a smooth curve (normally concave upward) from the "reduced" air pressure points (less than 21 psi) and extrapolate to intersect the 21 psi line. This intersection will not necessarily coincide with the "wettest" 21 psi point but will, more often than not, intersect somewhat to the right of this point (see example in Figure IV).

3. Since it is desired to obtain the most economical structural section which will safeguard against PCC curl, the final thickness of cover, over the expansive soil, will be primarily dependent upon the highest moisture level which can be attained in construction and still maintain workability or firmness of the working table to permit construction operations. Therefore, the next step, in this analysis, is to establish a minimum control moisture (MCM) content which will allow a reasonable range of workability up to a limiting moisture level. This is accomplished by determining from the previously plotted curves (on Form T-3051) which of the following three criteria provide the lowest moisture content:

a. Moisture content at the intersection of the reduced compactor air pressure curve with 21 psi air pressure (commonly referred to as "compactor pressure break-off point").

b. Moisture content at 30 R-value (as interpreted from the R-value curve).

c. Moisture content at 10 R-value minus 4% moisture.

4. After determining the MCM as the least of the above three moisture contents, refer to the inside scale on the left ordinate of Form T-3051 or the following Table I for allowable third cycle expansion pressure values corresponding to various depths below profile grade:

TABLE I

MAXIMUM ALLOWABLE THIRD CYCLE EXPANSION PRESSURES

Depth Below Profile Grade (feet)	*Third Cycle E. P. lb. per sq. inch*
1.5′	2.5
2.0′	3.1
2.5′	3.7
3.0′	4.3
3.5′	4.8
4.0′	5.3

5. Enter the abscissa of the chart at the MCM and note the intersection with the third cycle E.P. curve. Read the thickness of cover required, at this intersection, from the ordinate scale (to the nearest 0.1 foot). This is the design thickness of the structural section over the soil represented by the sample while the MCM represents the *minimum* moisture content which must be attained in the top one foot of the basement soil, during construction, for the particular thickness of structural section determined. In addition, the MCM must be maintained during construction until upper layers are placed to prevent the escape of moisture from the basement soil.

Notes

The above analysis processes are probably most effectively demonstrated by the use of examples. Therefore the following three examples are given in order to cover analysis situations which are most frequently encountered in practice. The first example is quite straightforward and demonstrates the basic principles of analysis. Examples 2 and 3 concern special situations when soils of low expansive potential are involved.

Example No. 1 (Figure IV)

The test data for the sample illustrated in this example is shown on the work cards in Figures I and II. Referring to Figure IV, this data is plotted on Form T-3051 and appropriate smooth curves are drawn through the respective points. The moisture contents related to the three criteria (see Section B-3 Items (a), (b), and (c) of this Part III) are then interpolated from the curves, as shown. These moisture contents are listed, for this example, as follows:

Moisture at compactor air pressure break-off point	=24.2%
Moisture at 30 R-value	=24.6%
Moisture at 10 R-value—4%	=29.0%

Since the compactor air pressure break-off point gives the lowest moisture value, 24.2%, this becomes the "minimum control moisture" (MCM). Intersection of the MCM with the third cycle E.P. curve indicates that 2.3 feet of cover will be required over soil represented by this sample.

Example No. 2 (Figure V)

This example illustrates a method for determining whether the expansive potential of a soil is sufficient to warrant any consideration from design and moisture control standpoints. It is noted that, in this case, the 10 R-value moisture minus 4% is the governing criteria and would be the MCM. However, it is also noted that the third cycle E.P. at this point is only 0.2 psi and at more than 2½% moisture below the MCM the pressure only raises to 0.9 psi. As a rule, when third cycle E.P. specimens, fabricated at least 2% moisture below the MCM, do not indicate third cycle EP's in excess of 1 psi, then the soil sample is considered *non-expansive* for the purpose of this test method.

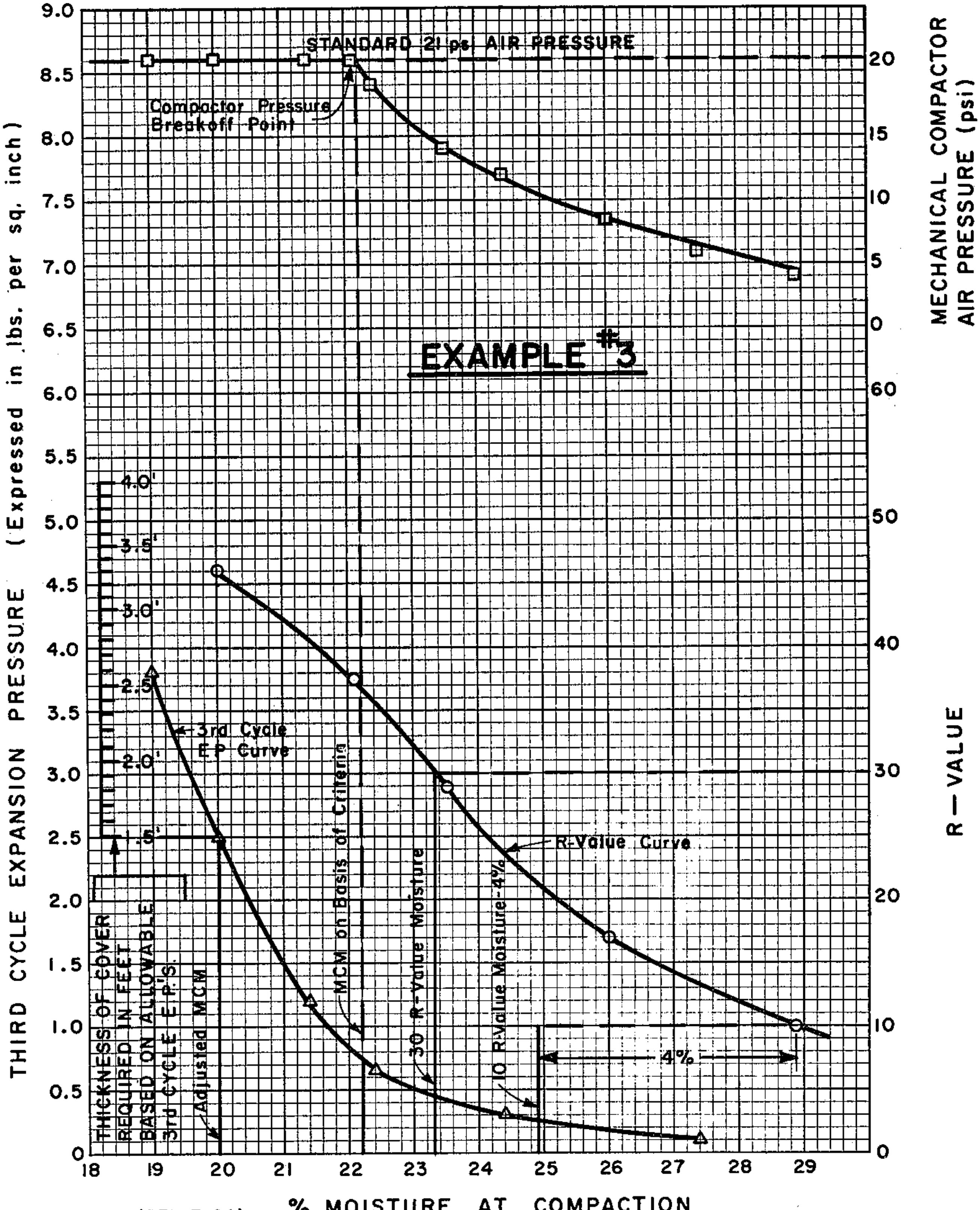
Example No. 3 (Figure VI)

The soil represented by this sample is also relatively low in expansive potential. It is noted that at

MATERIALS & RESEARCH DEPARTMENT

EXPANSION PRESSURE ANALYSIS OF SOILS UNDERLYING PCCP

PROJECT ______
W.O. NO. ______
SAMPLE NO. ______
DATE ______
CALC. BY ______ CHK. BY ______



FORM T-3051 (REV. 7-64)

Figure VI

State of California
Department of Public Works
Division of Highways

MATERIALS AND RESEARCH DEPARTMENT

Test Method No. Calif. 354-B
April 5, 1965
(10 pages)

METHOD OF TEST FOR EVALUATING THE EXPANSIVE POTENTIAL OF SOILS UNDERLYING PORTLAND CEMENT CONCRETE PAVEMENTS
(THIRD CYCLE EXPANSION PRESSURE TEST)

Scope

This method covers the procedure for performing the third cycle expansion pressure test upon soils which are intended to be incorporated in portland cement concrete (PCC) pavement structural sections. The method also includes the calculation of cover requirements along with the application of construction controls to safeguard PCC pavements against slab distortion (curling) caused by expansive subsoils.

This test method is divided into the following parts:

Part I. Modifications to Standard R-value Test as a Preliminary to Third Cycle Expansion Pressure Test

Part II. Method of Test for Determining Third Cycle Expansion Pressures

Part III. Method of Analysis for Design and Application to Construction Control

PART I. MODIFICATIONS TO STANDARD R-VALUE TEST AS A PRELIMINARY TO THIRD CYCLE EXPANSION PRESSURE TEST

The first test, which must be undertaken on soil samples submitted for expansive potential analysis, is the standard R-value test, Test Method No. Calif. 301.

The R-value test is performed in the normal manner except that additional specimens are prepared at moisture contents which will span the R-value range of 10 to 30 and will also show where the mechanical compactor foot pressure has to be reduced below 21 pounds. Some experience on the part of the operator is required to determine the range of moisture at the time of fabricating specimens. The following guides will assist the operator:

1. Fabricate at least two specimens at moisture contents low enough to provide firm specimens which will permit the use of full mechanical compactor foot pressure (350 psi) during the application of the 100 tamps as described in Part II, Section E-6 of Test Method No. Calif. 301. The moisture contents at compaction, of these specimens, should be arranged to span over a range of at least 3% moisture.

It is also desirable that the moisture content of the wettest specimen in this group should be as near as possible to the point where the compactor foot pressure must be reduced because of excessive penetration of the foot (see Part II Section E-7 of Test Method No. Calif. 301). Since the compactor air pressure, used to control the California type mechanical compactor, is directly proportional to the applied foot pressure, it is convenient to use air pressure values as expressions of foot pressure. Normally the compactor is calibrated on a load cell to provide the full 350 psi foot pressure at about 21 psi air pressure. Therefore, record 21 psi air pressure on the work card, Form T-361, where the full 350 psi foot pressure is used. Record necessary reductions in air pressure as proportionally decreased foot pressures are used.

2. Fabricate additional test specimens at moisture contents high enough to reduce expansion pressures to a negligible amount and also cover the range of moistures suitable for determining an R-value at equilibrium for the soil sample. Among this group of specimens there must be at least three specimens which, due to softness at the elevated moistures, require the reduction of foot pressure (recorded as compactor air pressure) to prevent the penetration of the compactor foot in excess of $\frac{1}{4}$ inch in accordance with Part II, Section E-7 of Test Method No. Calif. 301.

3. Exudation pressures are determined in the normal manner when specimens range between 100 (or less) and 800 psi exudation pressure. However, the specimens drier than the 800 psi exudation pressure level should be given only an 800 psi static load for leveling purposes. After compaction, subject all of the specimens to the normal expansion pressure and stabilometer phases of the R-value test (Calif. 301).

The standard R-value test series serves two purposes. First, it provides the equilibrium R-value of the material for stability determinations of the soil for the primary structural section design. Secondly, the individual R-value test specimens and the compactor air pressures are needed in the third cycle expansion pressure analysis for PCC curl potential. (See Part III). The requirements stipulated in items 1 and 2 above, regarding the compactor air pressures, are also essential for establishing the proper moisture range for fabricating both R-value and subsequent third cycle expansion pressure test specimens.

Record the R-value test data on the work card Form T-361 as shown in the example Figure I.

PART II. METHOD OF TEST FOR DETERMINING THIRD CYCLE EXPANSION PRESSURES

Procedure

A. Apparatus

The equipment and tools required for this procedure are the same as those described in Parts I to V, inclusive, of Test Method No. Calif. 301.

B. Test Record Form

Keep all pertinent data regarding the test specimens on individual test tickets (Form T-328W). Assign a ticket at the time of preparation of the material for the specimen, and keep it with the specimen until the third cycle expansion pressure test is completed. At the start of the third cycle expansion pressure test, copy all data onto the work card, Form T-361, as shown in the example illustrated in Figure II.

C. Fabrication of Test Specimens for the Third Cycle Expansion Pressure Test

1. Batch and compact from 4 to 8 test specimens in accordance with Test Method No. Calif. 301.

a. Arrange the moisture contents[1] of the individual test specimens to cover the range from about 600 psi Exudation Pressure and spanning the driest specimen as described for the R-value test under Part I of this test method.

b. Apply a 350 psi leveling load to all specimens.

D. Test Procedure

1. Allow specimens to set for at least one-half hour, after completion of the exudation test or application of the 350 psi leveling load, before proceeding with the following steps.

2. Clean off all dust and foreign material from the spring steel bar and gauge surfaces of the expansion pressure device.

3. Place deflection gauge in position on top bar of expansion pressure device. The single bearing end must rest on the adjustment plug.

4. Use an Allen wrench to raise or lower the adjustment plug until the deflection gauge is on minus 0.0010 in. (i.e., the large needle on the deflection gauge will point to number 9 on the dial face).

5. Place perforated brass plate with rod on top of test specimen.

6. Place mold on turntable after first placing a filter paper on turntable.

7. Seat perforated brass plate firmly on specimen with pressure applied from fingers.

8. Turn table up until the dial indicator reads zero.

9. Pour approximately 200 mls. of water on specimen in mold and allow to stand undisturbed for 16 to 24 hours.

10. At the end of the standing period, relieve any expansion pressure that has been developed[2] (1st cycle) by turning the turntable down until the rod on the perforated plate just barely breaks contact with the spring steel bar.

a. If, as a result of this relieving of pressure, the deflection gauge returned to the initial starting reading of minus 0.0010 in., then *immediately* raise the turntable until the deflection gauge reads zero. Allow to stand to for 16 to 24 hours.

b. If the deflection gauge does not return completely to the starting value of minus 0.0010″ (indicating that a set has been taken by the spring steel bar), then *immediately* use the Allen wrench to turn the adjustment plug and reset the deflection gauge to minus 0.0010″. Then turn the turntable up, to zero on the gauge as before. Allow to stand for 16 to 24 hours.

11. At the end of the second standing period (2nd cycle), relieve the expansion pressure which has developed and reset in accordance with paragraph 10-a or 10-b, whichever applies. Allow to stand for another 16 to 24 hours.

12. Read and record deflection gauge reading at the end of the *third standing period (3rd cycle)*. No correction should be made at this point for any set in the spring steel bar, which may be noted when the pressure is relieved by completely backing off the turntable.

13. Convert the dial reading into expansion pressure in pounds per square inch by entering the abscissa of the chart in Figure III and noting the expansion pressure, at the intersection with the diagonal line, from the ordinate scale. This is the third cycle expansion pressure value which is used in the analysis covered in Part III of this test method.

E. Precautions

1. The precautions concerning equipment cleanliness and vibration, as given in Sections F-1 and F-2, Part IV of Test Method No. Calif. 301, must be followed.

2. Since only highly expansive soils are normally subjected to this test, there is often a permanent set imparted to the spring steel bar as a result of the high expansion pressures developed. As a consequence, it is frequently necessary after the third cycle test to remove the bar, replace it in an inverted manner and recalibrate the device before using again.

3. The operation involved in making the "initial" gauge setting, as described in Section D-10-a or D-10-b of this test method, *must* be accomplished as *rapidly* as possible in order to minimize the detrimental effect of permitting the specimen to expand freely in an unconfined condition in the presence of free water. The time during which the specimen is unconfined at the end of the 1st and 2nd periods *must not* be more than 5 seconds.

PART III. METHOD OF ANALYSIS FOR DESIGN AND APPLICATION TO CONSTRUCTION CONTROL

Scope

In order to adequately safeguard a PCCP against curling, as a consequence of expanding underlying soils, it is necessary to employ both weight of cover to restrain expansion and the introduction of sufficient moisture into the soil to minimize its expansive potential. The use of the restraining weight of cover alone, without moisture control, is uneconomical and in many cases impossible where soils of high expansive potential are encountered. It is, therefore, the purpose of this design analysis to determine the thinnest structural section possible using moisture control within the limitations set by practical construction operations.

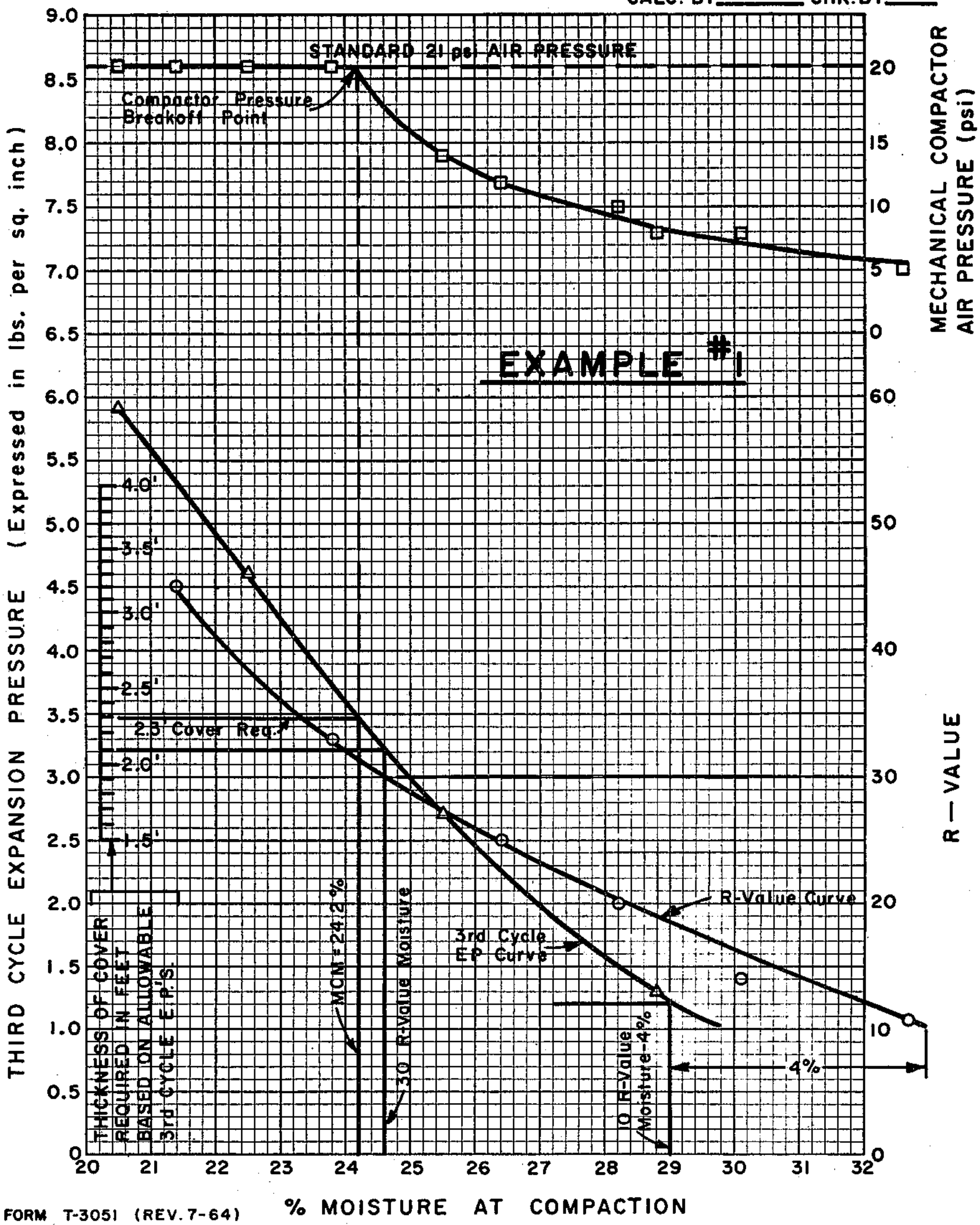
[1] It is neither necessary nor desirable, in fabricating the third cycle Expansion Pressure test specimens, to duplicate the moisture contents used in the R-value series. Selection of somewhat different moisture contents will provide additional points for interpreting compactor air pressure data in Part III of this Test Method.

[2] The expansion pressure readings at the end of the 1st and 2nd cycle are of no consequence to the purposes of this test method. However, they should be recorded for check purposes.

MATERIALS & RESEARCH DEPARTMENT

EXPANSION PRESSURE ANALYSIS OF SOILS UNDERLYING PCCP

PROJECT ____
W.O. NO. ____
SAMPLE NO. ____
DATE ____
CALC. BY ____ CHK. BY ____



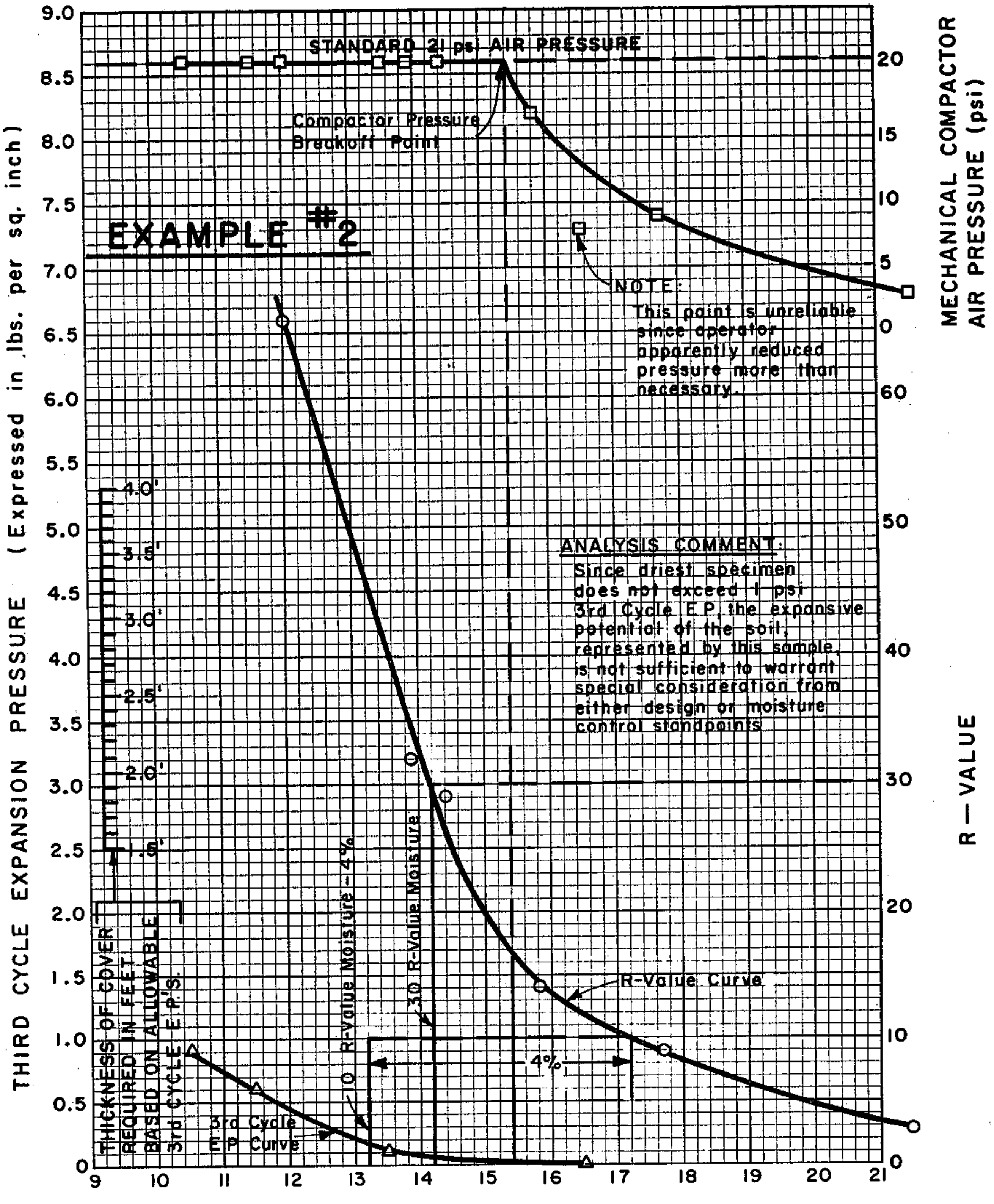
FORM T-3051 (REV. 7-64)

Figure IV

MATERIALS & RESEARCH DEPARTMENT

EXPANSION PRESSURE ANALYSIS OF SOILS UNDERLYING PCCP

PROJECT ____________
W.O. NO. ____________
SAMPLE NO. ____________
DATE ____________
CALC. BY ________ CHK. BY ______



FORM T-3051 (REV. 7-64)

Figure V

the controlling compactor pressure break-off point, the third cycle EP is 0.7 psi. However, unlike the previous example, the third cycle EP's increase markedly as the moisture content is reduced and will approach a cover requirement of 2.6 feet with a moisture reduction of about 3%. In this case, the design thickness should be established at 1.5 feet of cover and the MCM adjusted downward to coincide with the 1.5′ cover requirement. The "adjusted" MCM is 20% moisture in this example.

A situation similar to that demonstrated in Example No. 3, involving a sharply rising expansion curve, may occur where the driest specimen does not attain the level of third cycle EP represented by 1.5 feet of cover (but greater than 1 psi third cycle EP). In this instance, the design thickness would also be established at 1.5 feet of cover, but the MCM would only be adjusted to the moisture content of the driest specimen.

Occasionally a soil will be encountered which possesses such an extremely high expansive potential that the MCM intersection with the third cycle EP curve will be considerably above the level of the allowable pressure at the 4 foot cover requirement. Since the mechanisms which result in the PCC curl phenomenon are not considered to be effective beyond depths of 4 feet, structural design is not carried to greater thicknesses than 4 feet. However, some moisture control must still be maintained since excessively large volume changes may be expected from these materials if allowed to dry out. Therefore, the MCM should still be the ruling minimum moisture to be attained during construction.

REFERENCES

A California Method
Test Method No. Calif. 201
Test Method No. Calif. 301

End of text of Calif. 354-B